CONDENSED LIST OF MOST USED DATA

SURVEY DATA

ESTIMATE AND DESIGN DATA

HANDBOOK FOR HIGHWAY ENGINEERS

HANDBOOK

FOR

HIGHWAY ENGINEERS

CONTAINING INFORMATION ORDINARILY USED
IN THE DESIGN AND CONSTRUCTION
OF RURAL HIGHWAYS

BY

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THIRD EDITION
ENTIRELY REVISED, ENLARGED AND RESET

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PREFACE TO THIRD EDITION

The present revision was undertaken in response to the suggestions and requests of many users of the earlier editions. The practical value of the Handbook is increased by the addition of approximately 350 pages of new material covering mountain road location and design, camp equipment, medical notes, notes on photography, the selected soil and gravel treatment of moderate traffic roads, and the more recent developments of hard surfaced types. There is no change in the general scheme of the publication, which is primarily a compact collection of reference data and time saving tables. For the benefit of men not entirely familiar with the road problem, the discussion of principles has been retained, and in some cases where it has been shown that certain arguments in the previous editions have failed to make the impression warranted by their importance, the discussion has been amplified and illustrated by examples of construction and design. We wish particularly to emphatize gradeline design, which is not at present receiving the attention to which it is entitled, and also point out the practically universal lack of adequate maintenance.

The costs given in the body of the text are for comparative purposes only and are based on labor at from $0.175 to $0.20 per hour and material costs of the period 1912 to 1915.

For the improvement of future editions we request your coöperation in the correction of typographical errors, and the addition of any omitted data generally useful in road work.

Very few highway engineers are satisfied with the road legislation or technical practice of today or believe that it can be applied as it stands to solve the highway problem in this country in the next fifty years, but the data that has been collected from experience serves as a basis for future improvement. There is every reason to be optimistic in regard to road development provided the problem is approached with constructive imagination and encouragement is given to departure from methods whose main defense lies in precedent or habit.

The work of revision for this edition is entirely that of W. G. Harger.

W. G. H.
E. A. B.

Rochester, N. Y., January, 1919.

PREFACE TO SECOND EDITION

SINCE the publication of the first edition of this book four years ago, considerable progress has been made in the practice of road design and construction. To meet this advance, this handbook has been revised by bringing the material on top courses up-to-date, and by adding considerable data on tests, designs, costs, maintenance and specifications. Not only has much of the old material been revised, but new material, totaling approximately 100 pages, has been added. The criticisms and suggestions of many who have used the book in the field and office have aided the authors in this revision.

A more complete and systematic index has been prepared by Mr. Percy Waller.

The general arrangement of the book remains untouched.

W. G. H.
E. A. B.

ROCHESTER, N.Y., May, 1916.

PREFACE TO FIRST EDITION

THE purpose of this book is to collect, in a compact and convenient form, information ordinarily required in the field and office practice of road design and construction.

The book is designed to meet the requirements of both experienced and inexperienced road men. The material on the relative importance of the different parts of the design, and the possibilities of economy, without impairing the efficiency of the road, are primarily for the inexperienced engineer. The collection of cost data and the tables will be useful to any one engaged in road work.

As it is difficult to avoid clerical errors and mistakes in proofreading in first editions, we shall appreciate the coöperation of readers in calling our attention to any errors.

W. G. H.
E. A. B.

ROCHESTER, N.Y., April, 1912.

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INTRODUCTION AND GENERAL ANALYSIS

The highway question can not be treated as a local issue, as with limited funds it is often impossible to make improvements that are necessary to pioneer development, or that are suitable for modern long distance traffic. The national importance of the problem is recognized by the steady growth of State and Federal aid, which has already done much to improve engineering control and to increase financial resources. In many localities, however, it is still impossible to obtain enough money for proper design, and for these cases any solution is more or less unsatisfactory from an engineering standpoint.

Road design ranges from the low type earth roads of sparsely settled districts to the hard surfaced pavements of densely populated sections. For these extreme conditions the issues are clear cut; the first requires the greatest possible mileage with limited funds, and the last the most suitable design regardless of first cost. Intermediate cases are handled by merging the requirements presented by the extremes. A reasonable design for any case depends on the needs and resources of the local community, considered in connection with the importance of the improvement to the general transportation scheme of the country and the aid that will be granted on account of its general importance.

High type pavements should never be designed unless the community is able to provide its share of the construction cost by either direct appropriation, or short term, or serial bonds based on the probable life of the pavement, and in addition, to raise by some form of vehicle tax or direct appropriation its part of an annual maintenance and renewal fund of from \$500 to \$1000 per mile. States similar to New York, with an assessed valuation averaging \$240,000 per square mile and a population averaging 210 per square mile have demonstrated their willingness and ability to raise any amount required for the construction of the most suitable types of road, considering traffic conditions and economy of maintenance, but even these states have not yet made adequate provision for maintenance and renewal. States similar

to Wyoming, with an assessed valuation of $2000 per square mile, and a population of 2 per square mile, can not handle road construction in a conclusive way. They must adopt the method of progressive improvement. This represents the pioneer condition where the road question is most vital. Highways are a necessity to their development, and are considered primarily as a means of communication, not as pleasure routes, nor their improvement as a refinement to reduce the cost of transportation to a minimum. The people are willing to provide all the money they can afford, but expect some form of construction which will complete a line of communication to the point desired; a pack trail will do, a wagon trail is better, and an ordinary earth road will generally be accepted without question.

The same engineering principles apply to both conditions but the emphasis is different. Where the funds are practically unlimited, the problem is comparatively easy and is strictly technical. Where the funds are limited to inadequate amounts, the solution is more difficult; the engineer must decide where technical requirements should be retained and where ignored; he must plan the work so that whatever is done will become, if possible, a useful part of any future improvement, but above all a line of communication must be opened. In the design of high type roads the engineering emphasis is placed on safety, ease and economy of travel and maintenance. On pioneer roads the emphasis is placed on the selection of the best natural economic and engineering location and the greatest mileage for the funds.

We have therefore arranged the discussion of design practice from standpoints required for each case, and have indicated in the chapters on Grade, Alignment, Sections, etc., the road value of different limiting engineering requirements with their effect on construction cost.

ENGINEERING DESIGN

Functions of Grades, Alignments, etc.—A well-proportioned design considers the relative value and the object of the different engineering elements of the problem. In this connection we may say that grades, alignment and section are the most permanent and fundamental features of construction. The ruling grade largely controls the loads that can be hauled; section, grade and alignment combined determine the convenience of the road and the economy of earthwork, while alignment and section affect the safety and are also important factors in the appearance of the highway. For these reasons these three points must be ranked as equal and first in importance.

The next elements to be considered are drainage, foundation and top course, which keep the section firm and intact under traffic and weather action. Washouts are prevented and the bearing power of the soil is increased by surface and sub-surface drainage; the heavy concentrated wheel loads of vehicles are spread over a safe area of the sub-grade by the foundation course; the top course provides a surface that will withstand the abrasive action of

wheels and horses' shoes, that gives a good footing and offers slight rolling resistance. At the present time the problem of the top course is troublesome, on account of the conflicting demands of horse and automobile traffic. There is so much discussion of this one feature that it is easy to give it too much weight and there is a tendency to economize on the more permanent elements of construction in order to get a higher grade top. In the writer's opinion this is a mistake. The different top courses will be discussed in detail, but no definite conclusions can be drawn, as this part of the design is subject to constant change and improvement.

The Application of the Order of Importance of the Elements of Design to General Cases

Pioneer Roads.—Considering the policy of progressive improvement, limited funds should be expended as far as possible for essentials which will eventually become integral parts of the complete and finished design. The engineering requirements are listed below in their order of importance.

First.—Selection of the best general route.

(*a*) Best location for the development of the territory.
(*b*) Longest open season.
(*c*) Least rise and fall.
(*d*) Length and cost.

Second.—Selection of the most natural engineering location following the desired general route.

(*a*) Reasonable grades.
(*b*) Exposure. Avoid north exposure and areas of deep snow.
(*c*) Character of excavation. Avoid rock, slides, etc.
(*d*) Drainage problems. Avoid flood areas, stream crossings, etc.
(*e*) Avoid artificial restrictions such as section line locations, etc.

Third.—Detail requirements of design.

(*a*) Reasonable maximum grade.
(*b*) Economical intermediate grades.
(*c*) Safe and economical alignment.
(*d*) Width of roadway safe for traffic.
(*e*) Width of roadway convenient for traffic.
(*f*) Sufficient culverts and bridges to protect the roadway.
(*g*) Permanent construction of these culverts and bridges.
(*h*) Sufficient width of clearing for sun to reach road.
(*i*) Safety provisions. Protection for traffic at dangerous places.
(*j*) Provision of liberal width of right-of-way considering future widenings and development.

Fourth.—Improvement of the road surface.
(*a*) By selective soil treatment.
(*b*) By gravel, chert, caliche, etc.
(*c*) By hard surfaced pavements.

The following typical cases illustrate the usual problems that occur, and indicate their general solutions.

Where no road exists and the funds are entirely too small for good construction, a sufficiently cheap design is used to complete the entire length. Under these conditions the only requirement that must be met is the proper selection of general route, although it is probable that for the greater part of the distance the final engineering location can be followed. Considerable work of this kind has been done in New Mexico under the direction of State Engineer James A. French, and the solutions are ingenious. Satisfactory wagon and automobile trails have been constructed under favorable conditions for as low as $5.00 per mile (see page 130), while in difficult locations advantage has been taken of all possible expedients to keep the cost down.

Where a poor but usable road exists between the terminal points, or for a portion of the distance, either the uncompleted or worst sections of the route are first considered. Under such circumstances the funds are generally sufficient to permit a moderately good engineering design, which must provide for the proper final grade and drainage scheme on the improved sections, although the drainage structures may be cheap and temporary and the roadway narrow.

Where a fair road has been previously built over the entire route, no improvement should be attempted unless it provides for the best engineering design of grades, alignment, section and permanent drainage structures.

Where a first-class natural soil road is in use, the next step in progressive improvement requires either selected soil, gravel or hard surfaced construction of the traveled way.

Order of Work Pioneer Road Design.—The methods employed for the field and office work are described in Chapters X, XI and XIII. Engineering of this nature forms the most interesting class of highway work, and is handled in three stages.

A preliminary investigation is made to determine the general route, the best engineering location and the approximate cost of construction. It forms the basis for the general scheme of financing and design. It is the most important feature of new road location, and if well done insures the completion of a reasonable program of construction with the funds at hand. It also prevents wasteful expenditure on ill considered or unsuitable location surveys and plans. The detail location survey based on the preliminary conclusions is next made to secure the data for the final office design, which carries out in detail the recommendations of the first report and completes the work preliminary to construction.

Relative Order of Importance of Design Detail for Hard Surfaced Roads.—High type pavements in populous districts are necessary

to meet heavy traffic requirements. They reduce the cost of hauling and increase the ease and safety of light and heavy traffic. The parts of the design are more or less important in proportion to their necessity for the fulfillment of these purposes, and may be ranked as follows:

1. **Grades.**
2. **Alignment.**
3. **Sections.**
4. **Drainage.**
5. **Foundations.**
6. **Top courses.**
7. **Minor details.**

It can be seen by comparison that the details of hard surfaced road design have the same order of importance as for low type roads. The order of engineering procedure is also the same. The character of the information for the preliminary investigation is different, but the object is identical; namely, to provide a basis for appropriations and reasonable design. The preliminary data deals largely with probable traffic, available local materials and the most suitable and economical pavement type. The location survey provides the essential data for design, using somewhat better methods than for mountain conditions, and the office work is more detailed and complete. The methods are described in Chapters X, XI and XIII.

The application of the order of importance of design elements for hard surfaced pavement work can be shown by three cases:

Under the most favorable conditions outlined in the introduction, the improvement is considered final and its design is based on an effort to obtain the most useful, and in the end the most economical form of construction regardless of first cost. In this case all the engineering requirements may be fulfilled.

In many communities, however, the funds are only sufficient to build a moderately good pavement, which will have to be bettered by reconstruction in a few years, to meet the demands of the traffic. An improvement of this kind should be permanently and completely designed for proper grades, alignment, section, drainage and safety provisions, and the balance of the money spent on the best type of hard surface that can be afforded.

The third case is reconstruction, which usually confines the problem to considerations of the most suitable type of re-surfacing, utilizing previous work to the best advantage.

Maintenance and Renewal.—In presenting construction design for the approval of a community the cost of maintenance and the renewal of its temporary features should be fully explained in order that the cost of such work may be provided for. The amount required for adequate maintenance is rarely appreciated and the comparatively short life of any road surface is not a matter of general knowledge. Maintenance costs are discussed in Chapter VIII and the following Table No. 1 supplemented by Tables No. 21 and 22, Chapter VI, page 190, give a rough idea of the cost and length of life of the temporary features of typical hard pave-

ment types. Table No. 1 is based on 200 miles of 16 ft. width macadam and brick in Western New York. A well-designed earth road can be considered as 90% permanent.

TABLE I

	Brick		Bit. Mac.		Water Mac.	
	Cost per mile	% Total Cost	Cost per mile	% Total Cost	Cost per mile	% Total Cost
*Excavation	$2200	9.0	$1900	15.9	$1900	18.3
*Drainage Structures	700	2.8	700	5.3	700	6.7
*Foundations and sub-base	6300	25.9	3300	27.0	3300	31.7
.Surfacing .Edging	} 14700	60.1	5900	47.5	4000	38.5
.Minor points	500	2.2	500	4.3	500	4.8
*Total Permanent features	9200	37.7	5900	48.2	5900	56.7
. " Temporary features	15200	62.3	6400	51.8	4500	43.3
.Probable life " "	10 to 25 years		6 to 12 years		5 to 10 years.	

Road Bonds.—Extensive road programs are usually financed by long term bonds, fifty-year bonds being very generally used. This practice has been justly criticized, as large amounts of money will be required for construction renewals before the original bonds expire, except in the case of dirt roads. Serial or short term bonds, based on the probable life of the pavement, are more rational.

General Summary.—The general analysis may be summarized as follows:

The details of economic highway design are everywhere a local problem depending on the available materials, climatic conditions and traffic requirements. We know of no one who has had enough personal experience in the design, construction and maintenance of the various types under different sectional requirements to pose as an expert over any extended part of the country except on very general lines.

The chief factors which govern the cost of a highway system are legislative and finance programs which should provide the necessary money at the proper time; an engineering design which at all times should strive to use local materials to advantage, and a construction staff to insist on good workmanship. (The costs given below are based on labor and material costs prevailing from 1912 to 1916.)

1. The financing of many State systems of highways has never been well worked out for either construction or maintenance; what applies to them we believe is true of a large percentage of cases. A reasonable finance program depends on compliance with the following facts: The permanent features of a highway im-

provement are the grading, drainage and foundation. The surfacing is temporary even for the so-called "permanent" types. The rigid pavements such as brick, asphalt, concrete, etc. need resurfacing in from ten to twenty years; the macadam in from five to twelve years. The ordinary maintenance for the rigid types will run about $150 per mile per year with a resurfacing charge of $10,000 to $15,000 per mile at intervals of about 15 years. The ordinary maintenance on macadams is about $500 per mile per year with a resurfacing charge of $4000 to $6000 at intervals of seven to ten years. The ordinary maintenance of earth and sand clay roads runs from $30 to $150 per mile per year. The ordinary maintenance of gravel roads from $100 to $500 per mile per year. The yearly cost of maintenance and renewals amounts to from $50 to $500 per mile for earth, sand-clay and gravel roads and from $700 to $1000 per mile for macadams and rigid pavements. Provision for the necessary amounts is rarely made which results in a gradual deterioration of the roads and will finally occasion an unnecessarily large expenditure to put the systems back in good condition. Proper provision should be made for maintenance and renewal or a large future waste is certain to occur. A foresighted policy in this particular would save the community more than any economies of the design.

2. The engineering design rests on the consideration of construction, maintenance and renewal costs. In discussing this problem most of the current literature and highway speakers emphasize and confine economies to the selection of pavement type. This is a natural result of the exploitation of various materials and patent processes. As a matter of fact our experience indicates that for 75 to 80% of the roads the final cost is not greatly affected by the selection of type *except as it governs the use of local materials.*

In general the high and low priced pavements cost about the same, considering interest on first cost, maintenance and renewals. What is saved on first cost is spent on maintenance. The real engineering economies are limited to a careful grading and safe foundation design utilizing local materials, and to a selection of the cheapest first cost type of pavement of the general class required by the traffic; that is a rigid type for very heavy traffic and for all ordinary roads any type which will utilize local materials to their best advantage. On from 75 to 80% of the mileage of most State systems, any standard type of construction which will satisfy the traffic and which is the cheapest in first cost will generally be the cheapest in the end.

3. The inspection of construction has a marked effect on final cost and on public work there is a great variation in the care and knowledge of the inspectors. Well built macadams are much cheaper in the end than poorly constructed brick or concrete. The problem of improving inspection is a difficult one and the results appear to be spasmodic. If good inspection is not reasonably certain, the more nearly "fool proof" macadams are the most economical form of construction.

Value and Cost of Engineering Advice.—Sound financial and construction programs must be based on technical data and judgment. As a rule engineering advice is solicited and followed for the minor details of design and construction but is too often ignored or dispensed with in deciding on the general plan of action. This has resulted in patchwork systems; in poor legislative programs for maintenance and sometimes in a complete set back for highway improvements for a number of years.

The details of grade, alignment, section and drainage are usually solved on engineering principles except that in some localities the influence of patented culvert propoganda overcomes substantial design. The selection of pavement type however is often determined by popular vote or by the choice of non-technical boards. It is an unfortunate fact that very often communities, officials and engineers are susceptible to a continuous well planned advertising campaign and to the more or less proper and improper methods of approach of material salesmen, patented pavement promoters and influencial citizens. Current engineering literature is full of inspired articles and the rosy hued optimism is to use a slang phrase "pure bunk." Each well established pavement has certain advantages which are desirable under different conditions but the proper selection is a difficult matter which can be handled by an experienced engineer with better chances of success than if left to the limited knowledge of the community influenced by the silver tongued persuasiveness of the man with something to sell.

What, however, is more important is the preliminary layout of a comprehensive scheme of complete future improvement and the designing of each separate construction job as a part of the whole scheme rather than as a problem by itself. Hardly less necessary is the inauguration of a foresighted plan for obtaining enough yearly upkeep funds to prevent the partial or total loss of such improvements. This requires thorough preliminary study and the expenditure of considerable money for which there is apparently no immediate return, but so many ill considered, disappointing programs have resulted from the lack of this work that we can not overemphasize its importance.

At the present time road expenditures in the United States amount to approximately $300,000,000 per year and it can be said without undue criticism that the problem is entitled to more intelligent planning than it is now receiving. It is well worth the best engineering talent and sufficient initial expenditure to assure a workable scheme. Careless or inadequate investigation, survey and design are worse than useless and tend to discredit the value of engineering in connection with highway improvements. There is no doubt that any amount of money that may be required for thorough planning is justified by the resultant saving in construction cost and by the increased usefulness of the improvement but there is also no doubt that much of the money spent for inadequate engineering is absolutely wasted. This fact is recognized by the State and Government Departments which are conducting an educational campaign to raise the standard of highway work.

Satisfactory preliminary engineering costs from $100 to $300 per mile and amounts to about the same whether the proposed road is to cost $1000 per mile or $30,000 per mile. This is regarded with suspicion by men accustomed to figuring the cost of engineering as 2%, 4% or 6% of the construction cost but it should be borne in mind that it is more a mileage proposition than a percentage of construction proposition; that the cost is largely necessary for the location and grading design which is the same for low and high cost roads; that pioneer road location must consider the future development of the country and that the engineering cost in comparison with the amount of money which will immediately be spent on construction is of no importance whatever provided a proper location is made. Many of the older well settled communities are now suffering from originally poor road locations and it is hoped by all concerned that these mistakes will not be repeated in the construction of the new roads in the West.

Highway engineering in this country is still in the infant stage but growing lustily. It represents the systematic element of the road movement. The road improvement programs as expressed by current legislation are not logical nor could they reasonably be expected to be efficient as they represent a compromise between the conflicting ideas of earnest and flippant folks and profiteers. They contain a large element of humor and camouflage and a dash of efficiency. It is undoubtedly desirable to increase the percentage of efficiency somewhat but too much of that quality is not pleasing as popularly expressed by an unknown genius,

> "Who is it takes the joy from life and makes existence Hell,
> Who'll fire a real good looking one because she can not spell,[1]
> Who'll substitute a dictaphone for a coral tinted ear
> The penny chasing, dollar wasting efficiency engineer."

However, the fact remains that tax-payers desire to have their money spent with care and as there is rarely much difficulty in inaugurating a road program up to the limit of the financial ability of the community it seems well worth while to get the best results that are possible.

PART I

PRINCIPLES OF DESIGN

Order of Discussion.—The detail discussion of design will be taken up in the following chapters in their order of importance indicated on page 5 as follows:

Grades and Alignment.
Sections.
Drainage
Foundations.
Top Courses.
Minor Points.

CHAPTER I

GRADES AND ALIGNMENT

The subject of "Grades" may be treated under sub-headings of "Maximum," "Minimum," "Intermediate" and "Adverse."

MAXIMUM OR RULING GRADES

The following considerations govern the design of ruling grades:

1. The relative importance of horse and automobile traffic.
2. The difficulty of ascent and the ease and safety of descent.
3. The effect of length of grade on maximum load.
4. The theoretical advantage of certain grades.
5. The ruling grades in ordinary use and practical considerations governing their selection.
6. The effect of ruling grade on cost.

1. **Relative Importance of Horse and Automobile Traffic in the Selection of Grade.**—The remarkable development of mechanical transportation on rural highways entitles this class of traffic to every consideration within reason, but at the present time and for a long future period may reasons indicate that horse traffic will govern the selection of grade in most cases. This conclusion is based on the greater adaptability of team hauling to adverse conditions; on the probability that as long as stock is used for ordinary farm work it will be utilized to some extent for hauling even under conditions favorable for trucks; and on the fact that grades suitable for horses afford no hardship to mechanical outfits. All of the trucks and tractors in use have sufficient power to haul their loads on firm surfaced roads up any grade that would be selected for horse traffic and while a reduction in grade below these rates would reduce operating costs slightly, this consideration would hardly warrant any large expenditure at this time. The theoretical discussion is therefore developed on the basis of horse traffic.

2. Difficulty of Ascent and Safety of Descent.—The factors controlling ease and safety of ascent and descent have different values for different surfaces, but as most of the roads will in time be hard surfaced and as all parts of the design should fit into the final improvement, this part of the grade argument is made primarily for hard surfaced conditions.

European observers claim that on a stone road 5% is the maximum grade that can be descended safely by a trotting team without brakes and that 12% is the maximum that can be safely descended with brakes. By the use of the sliding shoe or locked wheels freighters in the Rockies descend 20% grades without much difficulty on ordinary natural soil roads. Safe descent with brakes need not be considered except in rare cases as it would result in a grade far beyond ordinary practice. Safe and easy descent without breaks is more important for light rigs than for heavy hauling but as this class of traffic has been practically eliminated by cheap automobiles it need not be given much weight. Descent, therefore, plays only a minor part in grade selection.

The writer knows of no careful records of actual maximum loads that can be hauled up different hard surfaced grades by an ordinary team; it is probably better to discuss this point theoretically as any experiments would be affected by too many variable local conditions to be worth much as a basis of comparison. As a check on the theoretical discussion records of loads on extreme mountain grades are given on page 16 which show that for all practical purposes, Table No. 7 of theoretical loads is fairly close and is on the safe side.

A summary of Prof. I. O. Baker's discussion of maximum team loads is given below, and through his courtesy we are enabled to include a collection of tables taken from his work, "Roads and Pavements."

Various trials have determined that the normal tractive power of a horse traveling three miles per hour for ten hours a day is approximately one-tenth of its weight; that when hauling up a steep grade it can exert one-fourth of its weight for a short time; that for a continuous exertion of one-fourth, the grade should not be over 1200 feet long and if over that, resting places should be provided every 600 to 800 feet; that in starting and for a distance of 50 to 100 feet, one-half of its weight can be used; and that the net tractive power ordinarily exerted by a horse on a grade equals (¼ its weight)—(the effort required to lift itself) or approximately $(0.25\ W) - (W \times \%$ of grade expressed in hundredths) *i.e.* $(0.25\ W - 0.04\ W)$ for a 4% grade. This undoubtedly gives a reasonable basis for ordinary hauling conditions but from data obtained by the author in connection with freight hauling in mountain regions it is evident that a good draft horse will exert more than $0.25\ W$ on moderately short sharp pitches of a long climb if allowed to rest at intervals of 200′ to 300′. The evidence indicates that a value of $0.35\ W$ is about right for such conditions.

Table 2 shows the effective power developed by an ordinary team of 1200 pound horses with moderate exertion and Table 2A

the power of a first class team of 1600 pound horses exerting their full strength.

TABLE 2.—ORDINARY STOCK MODERATE EXERTION

	Grade	Theoretical Net Tractive Effort	Tractive Effort in Pounds
W = weight of team, 2400 lb.......... P = per cent. of grade in hundredths	Level	0.10 W	240
	$2\frac{1}{2}$ %	0.25 $W-PW$	540
	4 %	0.25 $W-PW$	504
	5 %	0.25 $W-PW$	480
	6 %	0.25 $W-PW$	456
	7 %	0.25 $W-PW$	432
	8 %	0.25 $W-PW$	408
	9 %	0.25 $W-PW$	384
	10 %	0.25 $W-PW$	360

TABLE 2A.—DRAFT STOCK FULL POWER

	Grade	Theoretical Net Tractive Effort	Tractive Effort in Pounds
W = weight of team, 3200 lb......... P = per cent. of grade in hundredths..........	5%	0.35 $W-PW$	960
	6%	0.35 $W-PW$	928
	7%	0.35 $W-PW$	896
	8%	0.35 $W-PW$	864
	10%	0.35 $W-PW$	800
	12%	0.35 $W-PW$	736
	14%	0.35 $W-PW$	672
	16%	0.35 $W-PW$	608
	18%	0.35 $W-PW$	544
	20%	0.35 $W-PW$	480
	22%	0.35 $W-PW$	416

This power is used in overcoming axle friction, gravity resistance and rolling resistance.

The axle friction is small amounting to three or four pounds per ton for American farm wagons.

Grade resistance (gravity) equals (load $\times$ per cent. of grade expressed in hundredths) and expressed in pounds per ton of load equals ($2000 \times P$).

The rolling resistance varies for different surfaces and for each surface depends on the diameter of wheel, width of tire, speed of travel and the presence or absence of springs on the wagon. The best diameter of wheels, best width of tires and the use of springs as they affect the ease of hauling for both farm and road use are problems for the wagon manufacturers.

Morin a French engineer concluded, from a series of careful experiments that the harder the surface of the road the less effect width of tire had on rolling resistance. We are arguing from the standpoint of comparatively hard surfacing and are dealing with small differences in wheel diameter and can disregard these factors. As a matter of interest Tables 3, 4 and 5 are included to show the results of experiments on different soils and roads.

The question of wide tires affects road design chiefly in connection with the distribution of load over a safe area and will be taken up under "Foundations."

TABLE 3.—EFFECT OF WIDTH OF TIRE UPON TRACTIVE POWER[1]
RESISTANCES IN POUNDS PER TON

Ref. No.	Description of the Road Surface	Diameters of the Front & Rear Wheels respectively									
		3′-6″ & 3′-10″		3′-6″ & 3′-10″		3′-8″ & 4′-6″		3′-6″ & 3′-10″		3′-8″ & 4′-6″	
		Width of Tires									
		1½″	4″	1½″	4″	1½″	4″	1½″	3″	1½″	3″
1	Sod							283	239	189	228
2	Earth road (hard) ...		108					152	152	114	114
3	" " (muddy)		243	268	304	236	254			265	228
4	Sand " (hard)	199	162	171	164	141	168				
5	" (deep)	371	351								
6	Gravel road (good) ..			98	117	83	80			66	76
7	Wood Block (round)	51	49	61	70	35	46		54	28	38

[1] Pamphlet by Studebaker Brothers Manufacturing Company, 1892.

TABLE 4.—EFFECT OF SIZE OF WHEELS ON TRACTIVE RESISTANCE[1] POUNDS PER TON

Ref. No.	Description of Road Surface	Mean Diameter of Front & Rear Wheels		
		50″	38″	26″
1	Macadam, slightly worn, fair condition	57	61	70
2	Gravel road, sand 1″ deep, loose stones	84	90	110
3	" " upgrade 2.2%, one-half inch wet sand, frozen below......................	123	132	173
4	Earth road. Dry and hard	69	75	79
5	" " ¼″ sticky mud, frozen below ..	101	119	139
6	Timothy & blue grass sod, dry grass cut	132	145	179
7	" " " " " wet & spongy.....	173	203	281
8	Cornfield; flat culture across rows, dry	178	201	265
9	Plowed ground; not harrowed, dry & cloddy ..	252	303	374
10	Average Value of Tractive Power	130	148	186

[1] Experiments of Mr. T. I. Mairs at the Missouri Agricultural Experiment Station.

TABLE 5.—TRACTIVE RESISTANCE OF BROAD AND NARROW TIRES.[1] RESISTANCE IN POUNDS PER TON

Ref. No.	Description of Road Surface	Width of Tire		No. of Trials
		$1\frac{1}{2}''$	$6''$	
1	Broken Stone, Road; hard, smooth, no dust, no loose stone	121	98	2
2	Gravel Road; hard and smooth; a few loose stones	182	134	2
3	" " " no ruts, large quantity of sand	239	157	1
4	" " new gravel, not compact, dry	330	260	1
5	" " wet, loose sand 1" to 2½" deep	246	254	2
6	Earth Roads. Loam, dry, loose dust 2" to 3" deep	90	106	2
7	" " " dry and hard, no dust, no ruts, nearly level	149	109	3
8	" " " stiff mud, drying on top, spongy below	497	307	1
9	" " " mud 2½" deep, firm below	251	325	1
10	" " Clay, sloppy mud, 3" to 4" deep, hard below	286	406	1
11	" " " dry on top but spongy below	472	422	2
12	" " " dry on top but spongy below	618	464	5
13	" " " stiff deep mud	825	551	1
14	Mowing Land. Timothy sod, dry, firm, and smooth	317	229	1
15	" " " " moist	421	305	1
16	" " " " soft and spongy	569	327	1
17	Pasture " Blue grass sod, dry, firm, and smooth	218	156	2
18	" " " " " soft	420	273	2
19	" " " " " soft	578	436	1
20	Stubble " Corn stubble, no weeds, dry enough to plow	631	418	2
21	" " " " some weeds, dry enough to plow	423	362	1
22	" " " " in Autumn, dry and firm	404	256	2
23	Plowed " Freshly plowed, not harrowed, surface rough	510	283	1
24	" " " " harrowed, smooth, compact	466	323	1

[1] Missouri Agricultural Experiment Station Bulletin No. 39.

Table 6 gives the average rolling resistance in pounds per ton of load on different pavements for the ordinary farm wagon driven at ordinary speeds.

TABLE 6[1]

Kind of Pavement	Rolling Resistance in Lbs. per Ton of Load
Asphalt	30 to 70
Brick	15 to 40
Cobble Stones	50 to 100
Earth Roads	50 to 200
Gravel Roads	50 to 100
Macadam Roads	20 to 100
Plank	30 to 50
Stone Block	30 to 80
Wood Block	30 to 50

[1] Baker's "Roads and Pavements."

For a comparative estimate we will take a value of forty pounds per ton of load, including axle friction, on Macadams and Rigid Pavements and one hundred pounds per ton for earth roads in fair shape. The resistance to the effective tractive power of the team per ton of load is therefore $40 + (2000 \times P)$ on hard surfaced roads, and $100 + (2000 \times P)$ for earth roads, and the maximum load expressed in tons for any grade equals

$$\left(\frac{\textit{Effective tractive power of team for that grade}}{\textit{Resistance per ton of load for that grade}}\right)$$

Using the tractive powers of the ordinary team shown in Table 2, the following table is constructed. It is chiefly useful for a comparison of the effect of grade on load but all evidence indicates that the loads given correspond closely to practice. Table 7A shows loads for extreme team exertion as compiled in Table 2A. The loads given include weight of wagon.

TABLE 7

Grade	Effective Tractive Effort	Improved Roads: Resistance in lbs. per Ton of Load	Improved Roads: Maximum Load in Tons	Earth Roads: Resistance	Earth Roads: Max. Load
Level	240 lbs.	40 lbs.	6.0 tons	100 lbs.	2.4 tons
2½%	540 "	90 "	6.0 "	150 "	3.6 "
4 %	504 "	120 "	4.2 "	180 "	2.8 "
5 %	480 "	140 "	3.4 "	200 "	2.4 "
6 %	456 "	160 "	2.9 "	220 "	2.1 "
7 %	432 "	180 "	2.4 "	240 "	1.8 "
8 %	408 "	200 "	2.0 "	260 "	1.6 "
9 %	384 "	220 "	1.7 "	280 "	1.4 "
10 %	360 "	240 "	1.5 "	300 "	1.2 "

TABLE 7A.—DRAFT STOCK EXTREME EXERTION

Grade	Effective Tractive Effort	Hard Surfaced Roads: Resistance in lbs. per Ton	Hard Surfaced Roads: Maximum Load in Tons	Earth Roads: Resistance in lbs. per Ton	Earth Roads: Maximum Load in Tons
5%	960 lbs.	140 lbs.	6.8 tons	200 lbs.	4.8 tons
6%	928 "	160 "	5.8 "	220 "	4.2 "
7%	896 "	180 "	5.0 "	240 "	3.7 "
8%	864 "	200 "	4.3 "	260 "	3.3 "
10%	800 "	240 "	3.3 "	300 "	2.7 "
12%	736 "	280 "	3.0 "	340 "	2.2 "
14%	672 "	......	......	380 "	1.6 "
16%	608 "	......	......	420 "	1.4 "
18%	544 "	......	......	460 "	1.2 "
20%	480 "	......	......	500 "	1.0 "
22%	416 "	......	......	540 "	0.8 "

3. **Effect of Length of Grade on Maximum Load.**—In mountain road design where a long ruling grade is used it is often economical to introduce short stretches of steeper grade to avoid extremely expensive construction. In order to determine the maximum short grade (not exceeding 300 feet in length) that can be used in connection with a long ruling grade without reducing the team load we have compiled Table 7B for a 2400 pound team.

TABLE 7B.—EQUIVALENT LONG AND SHORT GRADES FOR HARD SURFACED CONDITIONS

Long Ruling Grades Tractive Effort 0.25*W* 2400-lb. Team		Short Maximum Grades Tractive Effort 0.35*W* 2400-lb. Team	
Grade	Maximum Load	Grade	Maximum Load
5%	3.4 tons	7%	3.7 tons
6%	2.9 "	9%	2.8 "
7%	2.4 "	10%	2.5 "
8%	2.0 "	*12%	2.0 "

* 12% is the practical limit (on account of safe descent) on any road of sufficient importance to be considered from an engineering standpoint.

This principle can also be applied to a long cut and fill grade reduction with a very material saving in cost but if used the steeper rate should not be over 250 to 300 feet long and should be at the bottom of the hill.

Records of Team Loads

We are indebted to Mr. H. G. McPheters and F. F. Roberts for the following data on team freighting in the Rocky Mountain

region. It is practical data obtained from personal experience and strengthens the force of the theoretical discussion. The loads given are net and do not include wagon weights. They represent usual freighting loads which are practical maxima.

HEBER FRUITLAND ROAD, STATE OF UTAH

Daniels Canyon Section

Earth road in fair shape.
Long 8% grades.
Short 15% grades.
Net load for four horse team 3500 lb. (during summer).

GALENA SUMMIT ROAD, STATE OF IDAHO

Natural soil road in fair shape.
Maximum grade (Salmon River side) 20%.
Maximum grade (Wood River side) 17%,
Load for one team 1800 lb. (during summer).
Load for two team 4000 lb. (during summer).
Load for three teams (six horses and two wagons loaded 5000 lb. on lead wagon and 4000 lb. on trail taking one wagon at a trip up the mountain).

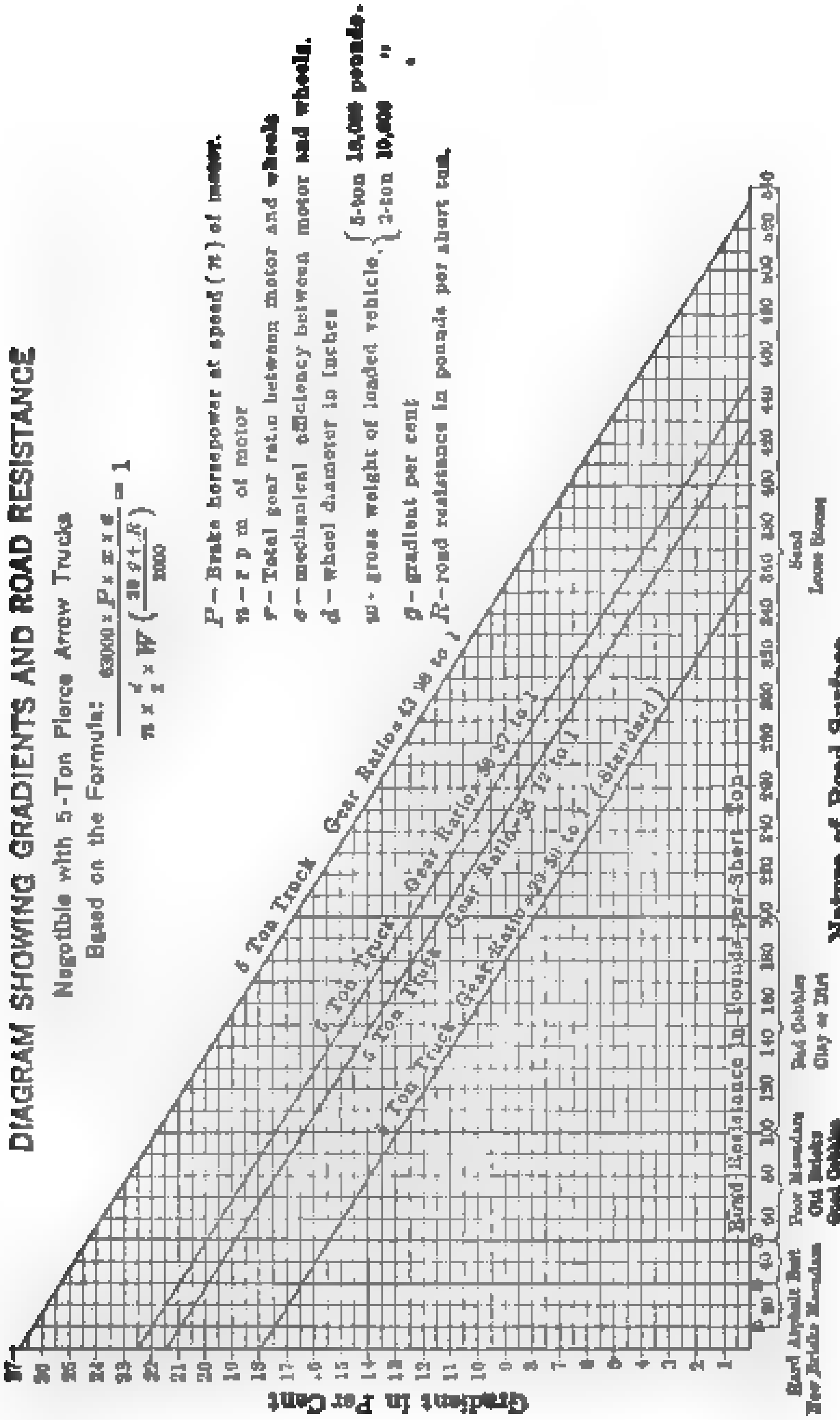
TRAIL CREEK SUMMIT ROAD, STATE OF IDAHO

Natural soil road (fair condition during summer).
Maximum grade 22%.
Load one team 1200 lb.
Load two team 2500 lb.
When freighting by teams was the principle mode of transportation, there were used on this road several outfits of twenty-four mules hooked to four wagons loaded about as follows: Lead 14,000 lb.; lead swing 10,000 lb.; swing 8000 lb. and trail 4000 lb. Two men handled the whole outfit which was certainly a man's job.

ROCKY BAR ATLANTA ROAD OVER BALD MOUNTAIN

Natural soil.
Maximum grade 16%.
Load for one team 2000 lb.
Load for two teams 4000 lb.
A large amount of freight is carried over this road by auto trucks at the present time.

Record of Truck Performance.—We are indebted to the Pierce Arrow Motor Car Company for the following charts which show the ability of their trucks to pull on different kinds of road surfaces and different grades when running on direct drive. This data confirms the previous statement that modern trucks have sufficient power to easily handle their full loads on any grade that would be selected for horse traffic on improved roads.



$$\frac{63000 \times P \times r \times e}{n \times \frac{d}{2} \times W\left(\frac{20g + R}{2000}\right)} = 1$$

CHART A.

OPTIONAL GEARING ON FIVE-TON MODEL

The first option is our standard gearing and will be supplied on all orders unless otherwise specified. This gearing should be used where the truck is to traverse good hard roads at all times, and where the grades do not exceed 10%.

The second option gives great pulling power on the low speeds, and the standard speed of 14 miles per hour on high gear. This gearing should be used only where the truck has to pull through a very short portion of poor road and the great majority of the running is done on direct drive. This option is popular with contractors, etc.

The third option is especially suited for districts where by nature of roads or traffic conditions a high speed is undesirable, or in hilly country, where the road surfaces are good. This gearing is standard equipment on the long wheel base model.

The fourth option should only be used where the road surfaces are exceedingly poor, and the country very hilly. We do not advise using this gearing except in extreme cases.

P—Brake horsepower at speed (n) of motor.
n—r p m of motor.
r—Total gear ratio between motor and wheels.
e—mechanical efficiency between motor and wheels, assumed as 70%.
d—wheel diameter in inches.
W—gross weight of loaded vehicle, 2-ton 10,000.
g—gradient per cent
R—road resistance in pounds per short ton

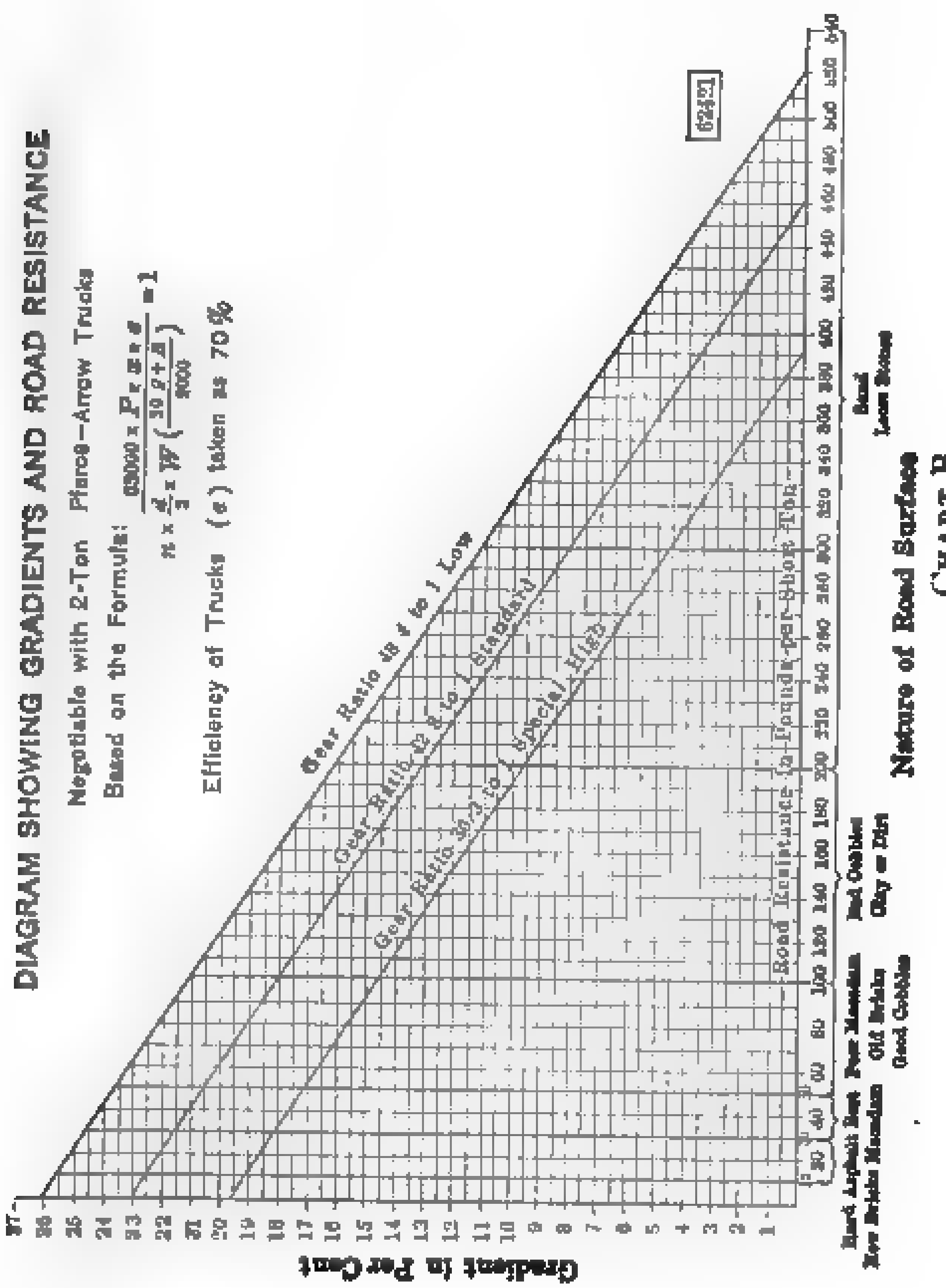


CHART B.

OPTIONAL GEARING ON FIVE TON MODEL

The first option is our standard gearing and will be supplied on all orders unless otherwise specified. This gearing should be used where the truck is to traverse good hard roads at all times, and where the grades do not exceed 10%.

The second option gives great pulling power on the low speeds, and the standard speed of 14 miles per hour on high gear. This gearing should be used only where the truck has to pull through a very short portion of poor road and the great majority of the running is done on direct drive. This option is popular with contractors, etc.

The third option is especially suited for districts where by nature of roads or traffic conditions a high speed is undesirable, or in hilly country where the road surfaces are good. This gearing is standard equipment on the long wheel base model.

The fourth option should only be used where the road surfaces are exceedingly poor, and the country very hilly. We do not advise using this gearing except in extreme cases.

4. **The Theoretical Advantage of Certain Grades.**—From Tables 7, 7A, 7B and the previous discussion we can pick out the grades that theoretically fulfill certain traffic requirements.

I. On hard surfaced roads the same load that can be drawn up a 2½% grade by reasonable extra exertion of a team, can be hauled on a level with ease. This makes a perfectly balanced design from the standpoint of team hauling. The theoretical load is six tons. For earth roads 5% fulfills this same condition with a theoretical team load of 2.4 tons.

II. 5% is the maximum grade that fulfills the requirement of safe descent at a trot without brakes. This is of little importance under modern traffic conditions.

III. The same load that can be hauled up a 7% hard surfaced grade can be drawn on a level dirt road in fair condition; a 7% grade therefore does not reduce the load of a team which must travel over an earth road for part of the distance. The theoretical load is 2.4 tons.

IV. The use of short maximum grades of greater rate than the long ruling grades does not reduce the maximum load provided they are proportioned as follows for hard pavements and do not exceed 250 feet to 300 feet in length.

Long.............	5%	Short...........	7%
"	6%	"	9%
"	7%	"	10%
"	8%	"	12%

V. 12% is the practical limit of grade for even unimportant roads on account of safe team descent with heavy loads.

As a matter of fact the selection of grade depends more on the requirements of the traffic and the topography of the country than on these theoretical advantages.

5. **Ruling Grades in Ordinary use and the Practical Considerations Governing their Selection.**—Various grades on country roads have been under observation for so many years that it is safer to be guided by present practice which is the result of such observation than to trust too much to a theoretical discussion. The adoption of the ruling grades shown in Table 8 has depended partly on the ease of maintenance as well as traffic considerations. The maximum grade on which different kinds of top courses can be safely used either on account of foothold for horses or the maintenance of the surface properly comes under a discussion of such courses and will be fully covered in Chapter VI.

In regard to the matter of safe team footing, it is possible to select some type of pavement which will satisfy this condition for any grade used but a change in surfacing to meet this requirement is often omitted on account of expense and more often omitted by careless design. Most of the rigid pavement types give satisfactory footing up to 5% which is the practical limit without special design. Bituminous macadams can, by variations in manipulation, be made suitable for grades up to 8%. Plain macadams give good

footing for any grade but are expensive to maintain over 5%. From the standpoint of footing 5% has a distinct advantage on main roads where rigid types are desirable, and 7% or 8% is a reasonable limit on side roads where some form of macadam or gravel will probably be used.

TABLE 8.—RULING GRADES IN FOREIGN COUNTRIES

Location	Mountainous Districts	Hilly Districts	Level Districts
Prussia	5 %	4 %	2½%
Hanover	4 %	3⅓%	2½%
Baden	8 %	6 %	5 %
Brunswick	5½%	4 %	3 %
Holyrod Road in England	6 %	3½%	
Military Highway over the Alps ...... Italian side ... 4½% Swiss side 6%			

Location	National Roads	Departmental Roads	Subordinate Roads
France	3%	4%	6%

RULING GRADES IN THE UNITED STATES

State	Main Roads	Side Roads	Unusual Cases
New York	5%	7 & 8%	11%
Massachusetts	5%	7%	
Connecticut	5%		
New Jersey	5%	6 & 7%	9%
Michigan	6%		
Missouri	5 & 6%		
Washington	5%	5%	
Illinois	6%		9%

United States National Forest Roads (Mountainous districts)				
First Class Roads	Long Grades	5%	Short Grades	7%
Second " "	" "	7%	" "	10%
Third " "	" "	10%	" "	12%
State of Colorado (Main Mountain Roads)				6%

From the standpoint of accommodating ordinary farm team loads 7% is the logical ruling rate. This is based on a load of 5000 pounds for farm hauling which includes wagon weight. The records of

produce dealers in the Eastern States show that the ordinary wagon weighs about 1350 pounds and that 3500 pounds is a large net load. This load of 2.4 tons corresponds with the maximum theoretical load for 7% hard surfaced grade. Team loads of six tons would be very unusual which means that the ideal teaming grade of 2½% need not be considered except in level country where it can be obtained without much extra cost.

From the standpoint of maintenance the cost of upkeep of ditches, shoulders and earth or gravel surfacing increases rapidly on grades above 5%.

From the standpoint of construction cost 5% to 7% can generally be built without excessive expenditure even in hilly country.

Practical considerations therefore indicate that for level country a 2½% maximum is desirable but does not justify large expenditures and that any grade up to 5% will probably be satisfactory; that in hilly or mountainous regions on the main roads, a long ruling 5% grade is the most satisfactory rate and warrants considerable expenditure but that 6% or 7% are reasonable if the funds are limited; that short stretches of steep maximum grades are allowable to reduce cost provided the element of safe footing is provided and the rate is properly proportioned and that on side roads 7% is generally satisfactory.

Grades as high as 11% have been constructed on State improved roads in New York and as high as 9% in New Jersey and Illinois but the general opinion of the Departments under which these grades were built is that they would not again use such a high rate except in villages where any material charge in street elevation would damage valuable properties. Outside of corporations it is bad practice to use long grades of greater rate than 7% for if any road is of sufficient importance to warrant engineering plans for the future it is certainly of sufficient importance to warrant a reduction in grade to a reasonable rate.

In any case the design should be consistent. Take for example a road between two shipping points. It is first necessary to determine the portion tributary to each terminal and then the practical grades on all the hills on each portion in order to decide what consistent ruling grade can be adopted without excessive cost (see example, page 329). There is no object in reducing a hill from 7% to 5% with a large expenditure if nearer the terminal there is a grade that can not be reduced below 7%. It should be borne in mind, however, that the nearer you approach the shipping or market point, the more traffic the road will have, and if the hills are naturally flatter the ruling grade should be reduced. The direction of heavy traffic on each hill should be determined and considered.

Effect of Ruling Grade on Cost.—Money spent on the reduction of ruling grade is never wasted although it is not good policy to spend large sums to reduce below 5% in hilly country or 2½% in level country. The effect on cost of the selection of a 5% in place of a 6% or a 6% in place of a 7% depends largely on the method of construction that must be used. Where locations are

fixed by well established right-of-ways and permanent structures and the cost of new right-of-way is very high grades are generally reduced by cut and fill. Under these conditions the effect of the selection of rate is very marked and no general relation can be established as each case is a law unto itself. To show the fluctuating amounts of excavation per mile for different improvements based on different rates of ruling grade where cut and fill was used, Table 9, page 30, has been compiled.

Unfortunately many of the roads in the older states were not laid out on natural engineering locations and grade improvements

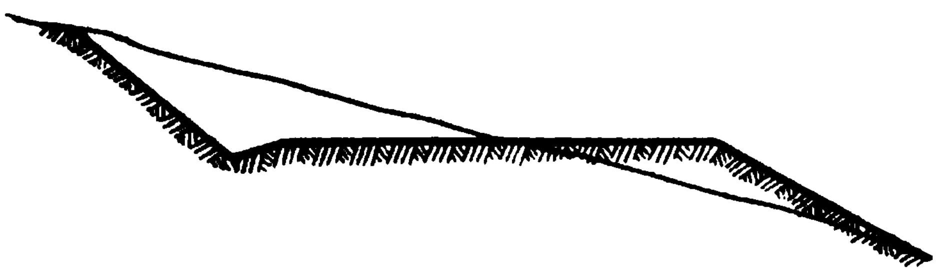


FIG. 1.—Balanced sidehill section.

are expensive either on account of excessive cut and fill or the high cost of new right-of-way on a better location. In mountain road or ordinary locations in newly settled districts the question of right-of-way rarely handicaps the design and easy grades are obtained at moderate cost by natural locations which avoid steep adverse grades by going around a hill or develop moderate grades on a long climb by a longer distance. In climbing on a sidehill location the road section is generally what is known as a balanced section, that is, the cut just makes the fill by side displacement. The amount of excavation per mile is not affected by the rate of grade but usually the length of road is affected.

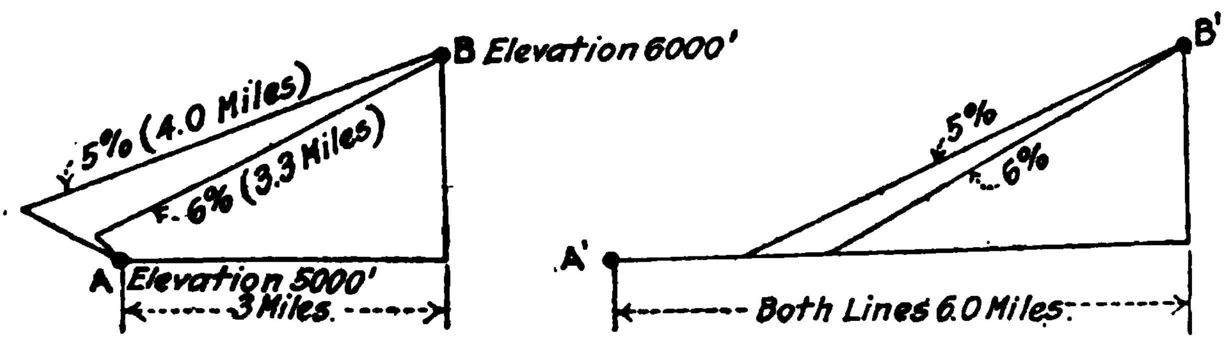


FIG. 2.

Generalizing we can say that the effect of grade reduction on cost is not as marked as for cut and fill methods and that roughly the relation of cost to grade depends on the length which is often inversely proportional to the rate; that is, where cut and fill is used a 5% grade might easily cost three or four times as much as a 6% grade but where sidehill location is possible a 5% would rarely cost more than 6/5 as much as a 6%. This is of course affected by all sorts of local conditions and may not apply at all but is true by and large and serves to illustrate the relation of rate to

cost. To illustrate: If the difference in elevation between *A* and *B* is 1000 feet a 6% grade would require approximately 3⅛ miles of length and a 5% grade 4 miles to make the ascent. If the direct distance between *A* and *B* is less than 3⅛ miles the lengths of the two lines will be approximately as given. If the distance from *A* to *B* is more than 4 miles there would be little difference in the length as it would merely mean that the 5% started to climb sooner than the 6%. Under most conditions the cost would be more affected by the character of the excavation on the different locations and by the number of switchbacks required for the smaller rate. *The difference in cost due to the difference in rate of ruling grade in mountain location does not often warrant the adoption of excessive grades.*

No criticism of wasteful expenditure on ruling grade can be made in regard to most of the plans as now designed but in many instances the profile feature of intermediate grades is not intelligently handled.

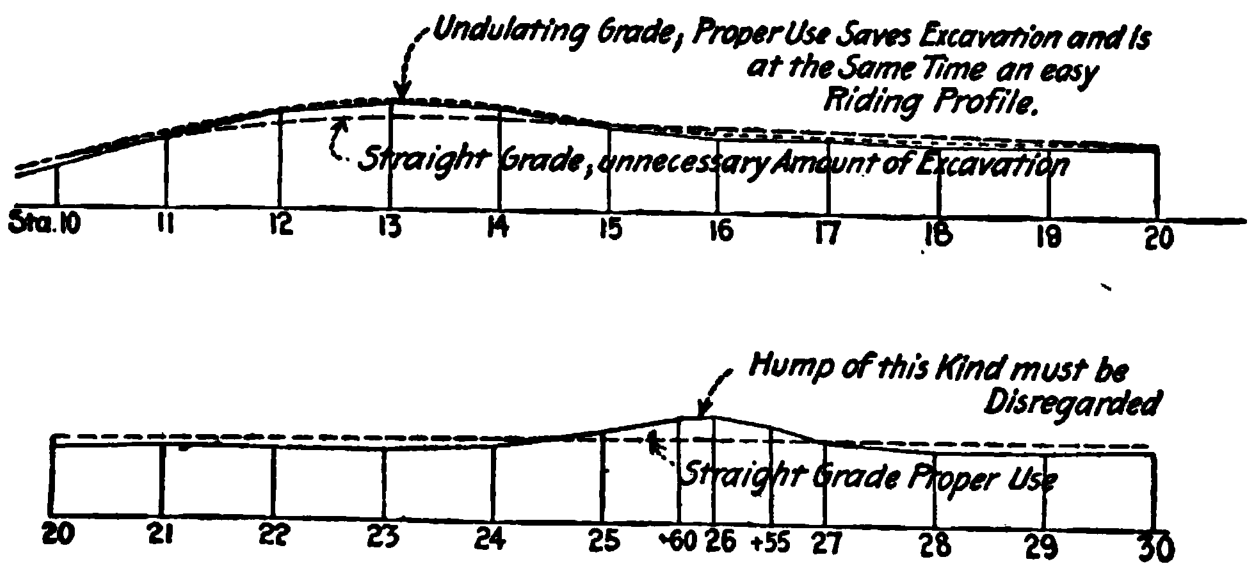
Intermediate Grades.—Intermediate grades include all rates between the ruling and minimum grades for the particular job in question. They afford the greatest chance for reasonable economy of earthwork of any part of the grading design and usually receive the least attention. From the standpoint of traffic they have no road value; their proper use however controls the convenience and suitability of the road to abutting property and controlling conditions. In laying a profile grade the controlling points must first be considered; these are highwater levels of flood areas, elevations of existing bridges, railroad crossings, all points where deep cuts or high fills would damage the approaches to valuable property; connections with other highways, portions of the road previously improved and in villages the elevation that will permit future widening and curbing that will fit the case.

Current practice handles most of these controlling features intelligently with the exception of grades through villages which are almost without exception too high for future widening and curb finish. Designers are cautioned to use city street methods and to make the elevation the same as if a full width curbed pavement was being designed.

Effect of Intermediate Grades on Cost.—All of these controlling points must be satisfied but they usually affect only a small percentage of the length of any improvement and on the greater portion of the road the most economical elevation and any intermediate rate of grade can be used. A grade so established that the cut in every cross-section would just make the fill at that point would result in the least possible excavation and the cheapest kind of grading methods. This condition can never be realized but the nearer it is approximated the nearer we get to the most economical grading design. Where intermediate grades are applicable there is no restriction on any combination of rates as they have no effect on traffic loads and by an intelligent selection the ideal solution can be closely approximated. The cheapest and most satisfactory profile can be obtained by the use of the "*rolling grade;*" by this is meant a profile made up of a combination of simple, compound,

or reverse vertical curves, connected by tangent grades only when the tangent grade is the most economical or is necessary to prevent a series of short humps and hollows. Long straight grades are not required a mistake easily made by engineers trained in railroad work. Short grades are not objectionable and reverse vertical curves ride easily if well built. The rolling grade is also more pleasing in appearance than a straight profile if not carried to extremes. It appears that there is too much tendency to cut the top of each knoll and fill each hollow for it is certainly a waste of money to reduce a natural 4% grade to a 3.5% or a 3.5% natural grade to a 3% if the ruling grade is 5%.

We can not overestimate the importance of this principle as the plans of about 2000 miles of road constructed in the last ten years which the writer has looked over in this connection show a needless expenditure of at least a million dollars for grading which had no



Illustrating Proper Use of Straight and Undulating Grades.

FIG. 3.

practical value whatever. This element of poor design in current practice is probably due to the fact that the savings are not spectacular at any one place but if the principle is consistently used the total result is spectacular.

It is also undoubtedly true that the previous railroad training of most road engineers and college instructors has had a detrimental effect on intermediate profile design. The author has personally applied the "rolling grade" principle on construction work for the last seven years and found that the saving averaged about $500 per mile. An intelligent grade line design will also often change the method of grading as well as reduce the yardage. To illustrate we will cite the Heber Fruitland Road in Utah. The original design used long straight railroad grades which required wagon haul; the redesign used a rolling grade which not only reduced the amount of excavation by about 30% but also practically eliminated wagon haul for most of the work and made it possible to handle

the dirt with slip scrapers and road machine blade scrapers. This reduced the cost per cubic yard about 25%. The quantity reduction plus the unit cost reductions amounted to approximately 50%.

The Effect of Arbitrary Profile Limitations on Cost.—A common grade line limitation calls for tangent grades drawn to intersection with simple vertical curves easing off the apex and insists on 100′ of tangent grade between the ends of these vertical curves. This sounds scientific but has no practical value and is cited to illustrate the danger of ill considered limitations. A specification of this kind often increases the grading by from 500 to 1000 cu. yd. per mile an example of which is given below.

PITTSFORD—N. HENRIETTA ROAD IN NEW YORK STATE

Length 2.67 Miles

ORIGINAL DESIGN	REVISED DESIGN
Maximum Grade 5%.	Maximum Grade 5%.
Profile.—Straight grades with 100′ of tangent between vertical curves.	Profile.—Rolling grade.
Original amount excavation 11,450 cu. yd.	Revised amount 9300 cu. yd.

(A saving of 800 yd. per mile.)

In conclusion we may say that the matter of intermediate grades needs more care than it is at present receiving.

MINIMUM GRADES

Hard Surfaced Pavements.—Most road books claim that level grades should not be used because of the liability of water standing in ruts and that a certain minimum grade should be adopted that will insure their longitudinal drainage. Baker states in his "Roads and Pavements" that for macadam roads English engineers use a minimum grade of 1.5%, French engineers 0.8% and that American practice favors 0.5%. Let us see what this means.

For a 1.5% grade the fall would be 1/5 inch per foot
For a 0.8% grade the fall would be 1/10 inch per foot
For a 0.5% grade the fall would be 1/16 inch per foot

The flattest crown that is ordinarily used even on bituminous macadam is 3/8″ per foot or twice as much as the greatest longitudinal fall in the above list. For long ruts the longitudinal grade is of course effective but the patrol system of maintenance is supposed to prevent their formation and for short small depressions the crown slope must furnish the drainage. There seems to be no reason

why level grades should not be used on hard surfaced roads; on such stretches the crown can be increased slightly to insure transverse drainage and the ditches given a minimum longitudinal fall of 0.2′ to 0.5′ per 100 ft. depending on the soil to insure the longitudinal drainage of the surface water.

Earth Roads.—On earth or gravel roads attention should be given to minimum grades as for these types they have some value but not enough to warrant much expenditure.

It is advisable to use a 0.4% to 0.5% grade where much snow or rain occurs but in the arid regions no minimum restriction should be specified.

ADVERSE GRADES

Adverse grades are defined as grades contrary to the general rise and fall of the road between terminals or controlling points. It is important to avoid them on mountain road locations where the prime object is to gain elevation. They are not a drawback in ordinary rolling topography. This is so self-evident that it hardly seems necessary to state it. There is no serious objection to short adverse grades even on a long climb if by their use the alignment can be bettered and excavation saved in crossing a small gully; the main objection is to long adverse grades introducing considerable additional rise and fall which could be avoided by a better engineering location. This point is generally considered in the selection of the general route and is covered by the comparison of routes in the preliminary investigation.

Grades, Summary.—The discussion of grades may be summarized as follows:

The road value of ruling grades can not be overestimated. Any expenditure on this feature is justified so long as it is consistent. The use of properly proportioned short maximum grades in connection with long ruling grades is the greatest source of justifiable economy.

Minimum center line grades have no road value on hard surfaced roads and only a slight value on earth roads. Minimum ditch grades are important.

The traffic value of intermediate grades is negligible but their importance in economical design is large. The greatest faults of present practice are the needless reduction of light natural grades and the use of long straight railroad rates.

Steep grades must be modified for sharp alignment which is discussed in the following text.

TABLE 9

PART 1. — COMPILED FROM THE 1908 AND 1909 REPORTS OF THE NEW JERSEY HIGHWAY COMMISSION.

Name of Road	Length in Miles	Maximum Original Grade	Max. Improved Grade	Excavation in cu. yds. per Mile
May's Landing	14.0	7.0%	3.2%	2,220
Rivervale	5.0	8.5%	5.0%	4,680
Westwood	1.2	5.2%	4.5%	2,500
Franklin Turnpike	1.6	8.0%	2.8%	8,200
Summit	1.9	13.0%	6.5%	5,200
Lamberton	3.9	2.8%	2.8%	540
Westfield	3.1	4.5%	2.9%	6,500
Blue Anchor	2.3	2.5%	2.0%	3,200
Malaga	5.7	4.2%	2.0%	1,700
Whitehouse	6.5	12.5%	5.0%	4,100
English Creek	6.7	6.0%	3.9%	2,000
Paterson Plank Road	2.3	Level	Level	(Emb.) 50,000
Yesler Way	2.7	12.0%	6.5%	5,700
Camden	2.4	6.7%	4.0%	5,200
Evesham	2.4	6.4%	3.7%	3,500
Schellenger's Landing	2.1	3.4%	1.1%	5,000
Goshen	2.6	3.4%	1.4%	4,500
Tuckahoe	4.3	4.1%	1.6%	8,100
Hopewell	2.0	7.6%	5.0%	3,800

TABLE 9

PART 2. — COMPILED FROM THE RECORDS OF THE NEW YORK STATE HIGHWAY COMMISSION.

Plans for 1911

Name of Road	Character of Country	Maximum Improved Grade	Width of Section between Ditches	Exc. in cu. yds. per mi.
Pittsford — North Henrietta	Rolling	5.0%	24'	2500
Indian Falls — Corfu	Flat	2.6%	24'	2800
Pembroke — East Pembroke	Hilly	5.0%	32'	3600
Livonia — Ontario County Line	Hilly	8.0%	32'	5500
Livonia — Lakeville	Hilly	8.0%	32'	4500
Avon — Lima	Hilly	8.0%	32'	3300
Sea Breeze — Nine Mile Point	Hilly	8.0%	26'	6600
Bliss — Smith's Corners	Rolling	5.5%	26'	3400
Wales Center — Wales	Hilly	8.0%	28'	5700
Scottsville — Mumford	Rolling	5.0%	32'	3400
Ridge — Rochester — Sea Breeze	50% Flat 50% Hilly	1.5% 5.0%	32' & 44'	3350
Medina — Alabama	Rolling	5.0%	28'–32'	2800
Pavilion — Batavia	Hilly	10.0%	22'–30'	2950
Parma Corners — Spencerport — North Chili	Flat	6.0%	32'	2320

TABLE 9. *Continued*

COMPILED FROM THE RECORDS OF THE NEW YORK STATE HIGHWAY COMMISSION.

Plans for 1910

Name of Road	Character of Country	Maximum Improved Grade	Width of Section between Ditches	Exc. in Cu. Yds. per mi.
Lake Part 2 & Sweden 4th Sect.	Flat	3.8%	32′	2560
Warsaw — Pavilion	"	5.0%	28′–32′	3900
East Henrietta — Rochester	Rolling	3.8%	32′	2300
Olean — Hinsdale	Flat	2.6%	28′–32′	4000
Leroy — Caledonia (1.5 miles)	Rolling	5.0%	32′–40′	1950
Shawnee — Cambria	60% Flat 40% Hilly	2.2% 7.0%	28′–32′	3150
Roberts Road	Rolling	3.1%	32′	3230
Sanborn — Pekin	Flat	2.4% One hill 5.0%	32′	2800
Oak Orchard, Part 2	Rolling	4.4%	30′–32′	2300
Levant — Poland Center	Hilly	5.0%	28′–32′	4000
Dansville — Mt. Morris, II	"	4.1%	24′	6200
Castile Center — Perry Center	Flat	3.6%	30′	2820
Lake Shore — Lackawanna City	"	0.7%	28′–32′	2120
Eighteen Mile Creek	Hilly	7.0%	28′–32′	6100
Albion Street — Holley	Rolling	3.7%	32′	3440
Pembroke — East Pembroke	"	5.0%	32′	3800

TABLE 9. *Continued*

COMPILED FROM THE RECORDS OF THE NEW YORK STATE HIGHWAY COMMISSION.

Plans for 1908 and 1909 (Selected Roads)

Name of Road	Character of Country	Max. Improved Grade	Width of Section between Ditches	Exc. in cu. yds. per mi.
Hamburg — Springville Sect. I	Rolling	6.0%	30′	1920
" " " II	Hilly	7.0%	30′	3100
Collins — Mortons Corners	"	7.0%	32′	2250
Clarence Center	Flat	2.5%	28′	2200
Orchard Park — Griffin's Mills	Hilly	8.0%	28′	2000
County Line	Flat	5.0%	28′–32′	2100
Geneseo — Avon	Hilly	5.3%	32′	2200
Geneseo — Mt. Morris	"	6.0%	32′	3460
Alden — Town Line	Flat	6.0%	22′–28′	1960
Pittsford — Mendon	Hilly	6.0%	32′	3000
Pittsford — Despatch	"	5.0%	24′	3600
Clover Street Section I	"	8.0%	28′	2550
" " " II	Rolling	4.5%	32′	3000
Rich's Dugway	Hilly	7.2%	20′–28′	5000
Left Fork — German Church	Rolling	6.2%	28′	2000
Goodrich Road	60% Flat 40% Rolling	5.0% 6.0%	26′–32′	3100
Hamburg — North Collins	Hilly	9.0%	22′–32′	4200
Lawton — Gowanda	"	7.5%	32′	5300
Chili	Rolling	5.0%	28′	2800
Brooks Avenue	Flat	4.6%	24′–30′	2240
Lyell Avenue	"	2.2%	26′–30′	2400
Barnard's Crossing	"	4.4%	22′	2174

TABLE 9. *Continued*

COMPILED FROM THE RECORDS OF THE NEW YORK STATE HIGHWAY COMMISSION.

Plans from 1898 to 1907. (Selected Roads)

Name of Road	Character of Country	Max. Improved Grade	Width of Section between Ditches	Exc. in cu. yds. per mi.
East Avenue	Rolling	5.0%	22′	8160
Pittsford	"	5.0%	22′	5840
Fairport	"	5.5%	20′–22′	6580
Ridge Road	"	3.3%	26′	2150
Buffalo Road	Flat	2.0%	22′–25′	1700
White's Corners Plank Road	"	3.5%	22′	4600
Orchard Park	"	3.9%	20′	4200
Transit, Sections I & II	"	4.6%	22′	2100
Hudson Avenue Road	Rolling	3.1%	22′	7100
West Henrietta	Flat	5.5%	22′	3400
Scottsville, Section I	"	4.0%	22′	2000
" " II	Rolling	5.0%	22′	2100
Monroe Avenue	Flat	4.5%	22′–24′	1850

TABLE 9

PART 3. — COMPILED FROM THE REPORTS OF THE MASSACHUSETTS STATE HIGHWAY COMMISSION. 1896

Name of Road	Length in Miles	Maximum Improved Grade	Width of Section between Ditches	Exc. in cu. yds. per mi.
Andover	0.6	4.9 %	24′	6000
Brewster	1.0	3.36%	21′	2607
Dalton	1.5	6.0 %	30′	1920
Gloucester	1.6	5.0 %	21′	3200
Granby	0.63	2.7 %	21′	5300
Great Barrington	1.0	2.6 %	21′–24′	2300
Hadley	1.49	4.0 %	21′	8930
Munson	0.93	2.95%	21′	3000
Norfolk	1.2	5.3 %	21′	3350
North Hampton	0.56	1.25%	26′	4300
Pittsfield	1.0	4.25%	21′	4700
Tisbury	1.93	4.40%	21′	7540
Westport	3.0	1.7 %	24′	1500
Wrentham	1.62	4.0 %	21′	3700
Walpole	1.61	6.0 %	21′	5600
Duxbury	1.05	3.8 %	21′	3800
Fairhaven	1.45	4.0 %	21′	1200
Fitchburg	0.97	6.0 %	21′	4500
Goshen[1]	1.91	5.0 %	21′	9700
Marion	1.48	5.0 %	21′	1500
Mattapoisett	1.16	4.25%	21′	1810
Lee	1.5	5.16%	—	3500
Leicester	2.0	5.0 %	—	3800

ALIGNMENT

High Type Pavements.—Alignment on this class of improvement is generally pretty well determined by existing rights-of-way. Changes are made for extremely unsafe conditions but otherwise this feature received comparatively little attention and has small affect on cost.

Sharp curves on steep grades or at the foot of such grades are not safe; good practice calls for a minimum radius of 300 to 400 feet for these cases. Right angle turns even on level stretches are inconvenient and often dangerous. New York State has adopted a radius of 200 feet as a minimum, wherever possible, acquiring new right-of-way when necessary, and it is very evident that the increased comfort has pleased the traveling public.

On comparatively straight stretches the position of the center line should be shifted to keep on the old roadbed as much as possible and yet give a pleasing appearance; this is done to utilize the hard foundation of the present traveled way for the sub-grade of the proposed metaling.

Sight Distances.—In designing a sidehill road, in rough country, the alignment and width of shoulder often depends upon what we may call "a safe sight distance," this means that the driver of a machine, traveling at ordinary touring speed of 20 to 30 miles per hour, must be able to see far enough ahead to turn out and pass an approaching car without the application of brakes. In attempting to reach a conclusion as to what is a "safe sight distance" we have written to automobile clubs throughout the country and find that, in the main, they agree on from 200 to 300 feet for speeds of 20 to 25 miles per hour.

Mr. George C. Diehl, Chairman of the Good Roads Board, A. A. A. and County Engineer of Erie County, N. Y., gave us the following information for emergency stops and passing without slowing up:

> "The tests that we have conducted show that a car going at the rate of 20 miles per hour can be stopped at 40 feet and one going at 40 miles per hour can be stopped at 140 feet with the emergency brake. For passing a rig going in an opposite direction this distance would not be necessary."

Mr. Diehl's figures are considerably less than the distances given in the other answers. A minimum sight distance of 250 to 300 feet in the practice of Division No. 5, New York State Department of Highways.

In the chapter on "Office Practice," tables are given showing the "sight distance" for different curves in "cuts."

Mountain Roads.—On mountain roads, alignment is given careful consideration as it has a marked effect on cost and safety. From eastern road standpoints very few of the mountain roads of the west can be considered safe for traffic. Extreme safety is prohibitive in cost and it is out of the question to attempt to fulfil the sight distance requirement cited above. Much can be done by widening sections at sharp curves and the so-called daylighting of curves shown in Figure No. 4 but a great deal must

be left to the care of the driver. The main advantage of the method shown in Figure 4 is that even if the driver hugs the wrong side of the road he can see ahead.

In alignment design the radii are made as large as possible to fit the mountain side without excessive grading. On steep slopes the grade contour must be followed closely. There is no hesitation in using radii as sharp as 80′ at the head of gulleys where the driver can see across the curve or a radius of 100′ on outside curves where the sight distance depends on the radius. Even these limits are impractical in very rough country where radii of 40′ are considered reasonable. All outside curves with a sight distance of less than 100′ should be posted with danger signs.

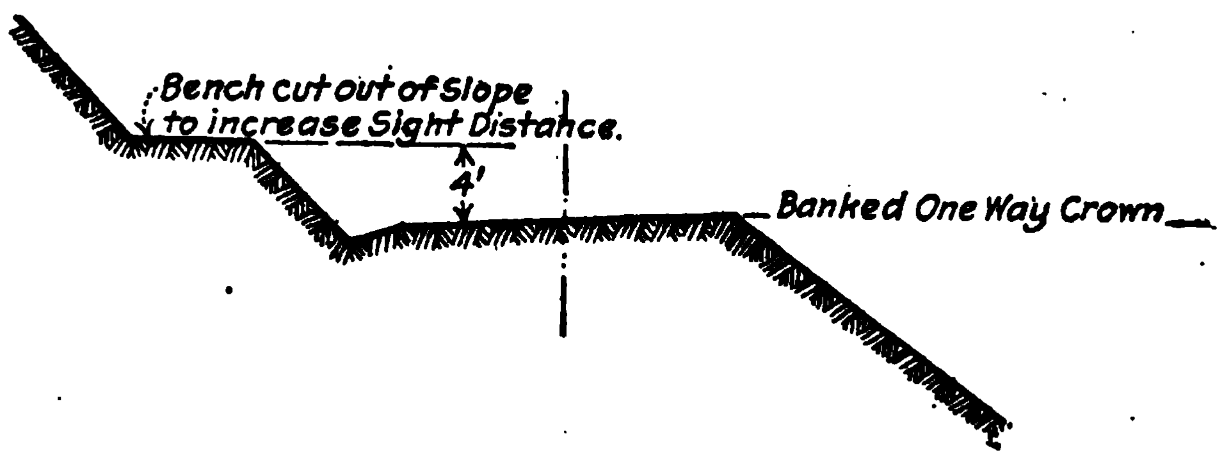


FIG. 4.—"Daylighting" a curve.

Effect of Alignment on Grade.—On sharp curves it is desirable for the driver to have first-class control on the score of safety. An extremely sharp curve with a large central angle also reduces the hauling capacity of a six horse team by from 20 to 40%. Considering both safety and team hauling it is therefore desirable to reduce ruling grades on sharp curves. These considerations have no practical value on mountain roads for curves having radii greater than 100′ but on sharper curves good practice recognizes this principle. Ordinary design uses radii of from 40′ to 80′ on difficult switchback turns. For a 40′ radius the grade should not exceed 3% and for an 80′ radius 4% is a reasonable maximum.

Effect of Alignment on Cost.—The arbitrary limitation of minimum radius has a large effect on cost. The following example will illustrate this point. These revisions were made by C. H. Chilvers on the Rabbitt Ears Pass Road in Colorado to show the effect of alignment on excavation.

The office method of plotting a good cheap alignment are described in detail in Chapter XIII.

Conclusion.—Alignment is important and worth careful study on new locations but becomes a minor feature where existing rights-of-way must be utilized.

RABBIT EARS ROAD, STATE OF COLORADO, SIDE HILL SECTION

Original Design	First Revision	Second Revision
Length 8.79 miles Width of roadway 16′ Maximum grade 8% Grades flattened on switchback turns Minimum radius 100′ First-class alignment throughout Total amount of exc. 91,000 cu. yd. First-class design but needlessly expensive	Length 8.81 miles Width 16′ Maximum grade 8% No grade compensation on curves Minimum radius 100′ First-class alignment but more curving eliminating many expensive tangents Amount of exc. 65,000 cu. yd. First-class design shows effect of careful intelligent alignment engineering	Length 8.94 miles Width 16′ Maximum grade 8.5% No compensation on curves. Minimum radius 40′ Poor crooked alignment carried to extremes Amount of exc. 38,000 cu. yd. Illustrates extreme effect of alignment on cost From an engineering point of view there was no justification for this design for the topography in question

NOTE.—On one switchback turn on this road a 100′ radius required 5000 cu. yd. exc. and a 40′ radius 500 cu. yd. or one-tenth as much. Short radii are justified in isolated cases but their continuous use to save small amounts is poor practice.

RAILWAY GRADE CROSSING ELIMINATIONS

Grade crossings are being eliminated as rapidly as possible as they are a source of danger. The overhead clearance and width of roadway in subways are given in Chapter XIII. Where a grade crossing is necessary the alignment should be straight and if it is necessary to approach the track on a grade this grade should not exceed 5% and the portion of the road for at least 50′ and preferably 100′ on both sides of the tracks should be practically level to permit the perfect control of a rig as it approaches the crossing. Anyone owning an automobile is familiar with the dangerous element of driving where precautions of this kind are not observed. The best examples of current restrictions in regard to grade and alignment at railway crossings are given in Chapter XIII.

CHAPTER II

SECTIONS

The date will be presented by discussion and examples of current practice for both High type roads in ordinary topography and for mountain conditions.

High Type Road Sections. (Ordinary conditions)

Discussion.—(Development of Standard Section.) Sections may be considered from the standpoints of safety, convenience and economy.

For safety a rig should be able to travel on any part of the road from ditch to ditch without overturning; for convenience the width ordinarily used by traffic must have sufficient pitch to drain the surface to the ditches but not enough to give an uncomfortable tilt to a vehicle; for economy the section must be flexible in order to conform to local conditions.

The first questions are naturally: What is a safe driving slope? What is a comfortable driving slope? What pitch is required to drain different surfaces? What are stable slopes for cut and fill back of the ditch line? What is the commonly used width, and what the maximum width of the traveled way?

All of these points except the last two have been pretty well determined, and, while some engineers disagree with current practice the writer believes from his experience and a study of various State sections that the following premises can be safely adopted:

That 3″ to 1′ or 4 to 1 is the maximum safe driving slope.

That 1″ to 1′ is the maximum agreeable driving slope.

That 1″ to 1′ is the minimum slope at which an earth shoulder will shed water without too much maintenance.

That ¾″ to 1′ or ⅝″ to 1′ is a satisfactory crown for a single track waterbound macadam and that ½″ is a satisfactory crown for a double track waterbound macadam.

That ⅜″ or ½″ to 1′ is a satisfactory crown for waterbound macadam having tar or asphalt flush coats or for bituminous macadams or mineral bitumen, double track roads.

That ¼″ or ⅜″ to 1′ is a satisfactory crown for brick, asphalt, concrete or any other rigid type of pavement used on country roads.

That stable cut and fill back slopes depend on the material and climate and range from ¼ : 1 to 4 : 1 as will be discussed later.

The width of roadway carrying the greater portion of the travel and the maximum width when rigs turn out to pass are not so well established; these two points determine the most economical width of hard pavement and the minimum convenient driving width no part of which should have a transverse slope of more than 1″ to 1′.

Probably the most systematic record of these widths can be found in the reports of the Massachusetts Highway Commission during the years 1896 to 1900 and while the data does not exactly apply to present traffic conditions it indicates the general relation between widths of heavy and light use. Table 10 gives the results on a few roads showing the form used and the variation from year to year; the footnote for Table 10 gives a summary of the observations on 160 roads for the years 1896 to 1899 inclusive; this brief was prepared by J. Y. McClintock, County Engineer, Monroe County, New York, and gives a better idea of the conditions than would be conveyed by printing the original table in full.

TABLE 10. SHOWING WIDTHS OF TRAVELED WAY

Town or City	County	Width of Macadam	Maximum Width of Traveled Way				Width of Commonly Traveled Way			
			1896	1897	1898	1899	1896	1897	1898	1899
Athol	Worcester	17′	16′	16′	20′	18′	10′–12′	12′	14′	14′
Barre	Worcester	15′	—	13′	14′	14′	—	9′	7′	8′
Bedford	Middlesex	15′	—	12′	15′	15′	—	8′	10′	9′
Chicopee	Hampden	20′	—	20′	20′	20′	—	12′	12′	13′
Dalton	Berkshire	15′	20′	20′	21′	16′–21′	20′	16′	18′	12′–18′
Fitchburg (W.)	Worcester	15′	15′	14′	18′	18′	10′	10′	15′	14′
Huntington	Hampshire	15′	9′	11′	11′	12′	7′	8′	9′	8′
Lincoln	Middlesex	15′	15′	15′	15′	15′	10′	9′	10′	10′
Marshfield	Plymouth	15′	14′	12′	11′	12′	8′	9′	7′	7′
North Adams	Berkshire	15′	10′–12′	13′	14′	15′–20′	8′–10′	9′	10′	12′
Orange	Franklin	17′	16′	16′	20′	20′	10′–12′	12′	15′	15′
Taunton	Bristol	15′	20′	20′	15′	18′	10′–15′	10′	8′	7′–12′

Width of traveled way on 160 roads in Massachusetts, measured during the years 1896, 1897, 1898, and 1899, and printed in the report of the Massachusetts Highway Commission for 1900.

The width of stone on these roads is given as 15′ wide on 130, 12′ wide on 3, and 10′ wide on 2. It should be remembered that the stone is put on very much thicker in the middle than at the edges.

The maximum width of traveled way as measured was as follows:

9 ft. wide on	2 roads	18 ft. wide on	23 roads
10 " " "	6 "	19 " " "	1 "
11 " " "	2 "	20 " " "	10 "
12 " " "	28 "	21 " " "	10 "
13 " " "	8 "	22 " " "	1 "
14 " " "	23 "	24 " " "	2 "
15 " " "	30 "	25 " " "	4 "
16 " " "	8 "	26 " " "	1 "
17 " " "	1 "	33 " " "	1 "

The width of commonly traveled way as measured was as follows:

7 ft. wide on	12 roads	14 ft. wide on	8 roads
8 " " "	17 "	15 " " "	13 "
9 " " "	25 "	16 " " "	2 "
10 " " "	32 "	18 " " "	4 "
11 " " "	10 "	20 " " "	2 "
12 " " "	30 "	22 " " "	1 "
13 " " "	3 "	25 " " "	1 "

Crown has a marked effect on width of heavy travel. A heavy crown such as ¾ to 1′ or 1″ to 1′ tends to concentrate the travel in

the center and is a detriment on a heavy travel road. With crowns of ½″ or less per foot there is no tendency to concentrate. For single track pavements where the traffic naturally stays in the middle a heavier crown is desirable as being easier to maintain; on double track roads ½″ or less should be used for both the convenience of traffic and the distribution of wear.

The author has measured a number of the New York State improved roads and found that the width of heavy travel checked the Massachusetts results but that the maximum widths were more averaging from 18 to 21 ft.; this probably can be explained by the increase in automobile traffic since 1900 which because of its higher speed requires more room in passing.

Briefly stated the widths subjected to hard wear on unimportant roads ranged from 8′ to 10′; on well traveled roads 10′ to 14′ and in unusual cases 14′ to 16′. The maximum widths varied from 12′ to 14′ on side roads to 17′ to 18′ on the main thoroughfares and as mentioned above have increased to 18′ to 21′ in the last few years. From this data it seems that the best practice at present requires

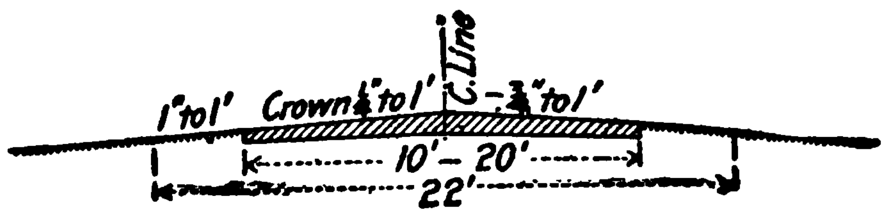


FIG. 5.

a driving width of about 22′ with a variable width of strong metalling determined by the traffic requirements and ranging from 10′ to 20′.

We have now practically developed a standard for the 22′ of driving width; the metalling that is to carry the heavy traffic has a specified crown for each variety and from the edge of the metalling to the limits of the 22′ the earth shoulder must have a slope of 1″ to 1′ or possibly ¾″ to 1′. The flexibility of the section depends on the portion outside of this 22′. The function of the extra width is to keep the longitudinal drainage of surface water beyond the portion used for driving. To do this we are limited to a minimum slope of 1″ to 1′ to insure transverse drainage and a maximum of 3″ to 1′ on the score of safety. It is by the good judgment of the designer in using various slopes between these limits and various widths and depths of ditches, combined with the possibilities of different grades that the economies in earthwork are effected and at the same time the design is made appropriate to the local conditions.

The author's experience has indicated that an open ditch does not have much effect on ground water; that its part in the design is to drain the surface water, thus preventing seepage into the roadbed with a resulting softening of the surface; and consequently whenever ground water is encountered under drains should be used. Deep ditches are not only useless but dangerous and the best practice calls for the least depth that will handle the surface water. Frequent

culverts are desirable to rid the ditches of excess water. It should be remembered that road ditches are to protect the road and not to furnish farm drainage and that deep farm ditches should be kept away from the road section. The following section is therefore suitable where there is no probability of much surface water; it is the writer's idea of the minimum width section which will be satisfactory, and where it can be adopted will give the most economical grading design for light cuts and fills.

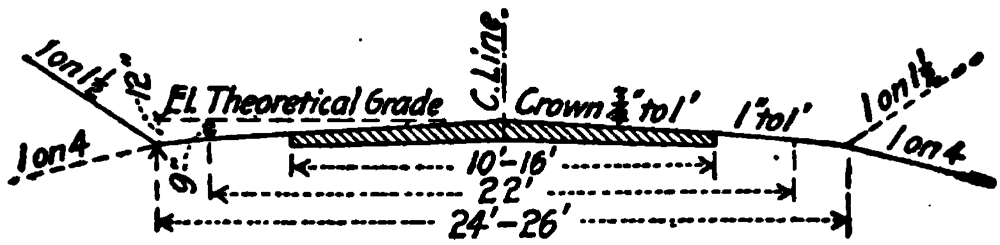


FIG. 6.

Effect of Grading Width on Cost.—The width of grading from ditch to ditch has a distinct effect on cost but no general relation can be established for the ordinary road improvement where an old road forms the basis for the new grading. Two examples are given to show the value of reasonable reduction in sectional widths.

1. INDIAN FALLS—CORFU ROAD IN NEW YORK STATE

ORIGINAL DESIGN	REVISED DESIGN
Length 1.85 miles	
NO CHANGE IN PROFILE	
No Change in Ratio of Cut to Fill	
Width of Macadam 14′	Width of Macadam 14′
" " Section 30′	" " Section 24′
Depth of Ditch 18″	Depth of Ditch 14″
Original estimated excavation 7500 cu. yd.	Revised estimated excavation 5200 cu. yd.

This change is section alone resulted in a saving of 2300 cu. yd. excavation or at the rate of 1240 cu. yd. per mile, or in money about $600.00 per mile.

2. PITTSFORD—NORTH HENRIETTA ROAD IN NEW YORK STATE

Length 2.67 miles

ORIGINAL DESIGN	REVISED DESIGN
Width of Section 30′	Width of Section 24′
Depth of Ditch 18″	Depth of Ditch 12″–14″
Ratio of cut to fill 1.35%	Ratio of cut to fill 1.25%
Maximum Grade 5.0%	Maximum Grade 5.0%
Profile—Designed with straight instead of rolling grades and tangents of 100′ between vertical curves.	Profile—Rolling grades and reverse vertical curves used.
Original estimated excavation 11,450 cu. yd.	Revised estimated excavation 6620 cu. yd.

A saving of 4820 cu. yd; 1800 cu. yd. per mile, or, in money, approximately $900.00 per mile.

The revised design on this road is a good example of what can be saved by the use of a section that fits the conditions, a rolling grade, and a ratio of cut to fill that we have found from experience to be sufficient.

Stable Cut and Fill Slopes Back of Ditch Line.—Economy of design and maintenance is affected by the selection of reasonably stable slopes. For the class of grading usually encountered on roads discussed in this portion of the chapter their effect on construction cost is not great and they do not generally receive much attention but for Mountain Roads cut and fill slopes are an important consideration in the design and their effect on cost are worth considering.

Table 25, page 285, shows the effect in detail of various cut and fill slopes on yardage of the ordinary sidehill mountain road sections. To illustrate the point we will quote one typical case for say an ordinary double track section (S–14) Table 25.

Natural Ground Surface Cross Slope	Approximate Yardage per Mile		
	Cut slope 1½ : 1 Fill 1½ : 1	Cut 1¼ : 1 Fill 1½ : 1	Cut 1 : 1 Fill 1½ : 1
5°	1,100 cu. yd.	950 cu. yd.	900 cu. yd.
10°	2,200 " "	2,000 " "	1,900 " "
15°	4,000 " "	3,600 " "	3,300 " "
20°	7,900 " "	7,000 " "	6,100 " "
25°		12,100 " "	10,200 " "
30°			19,600 " "

Occasional slides can not be avoided, but continual slipping shows poor design and makes both the maintenance costly and travel dangerous.

Stable slopes vary for different materials and for the same material under different climatic conditions. A combination of moisture and frost requires the flattest slopes for ordinary soils. On account of the great variety of circumstances affecting the design no hard and fast rules can be laid down but the following table, based on Railroad and Highway practice, indicates the slopes that are generally used. In this table and throughout the text slopes are referred to as 1½: 1, etc., meaning 1½ horizontal to 1 vertical. In some of the State Standard illustrations however slopes are shown as 1 on 1½ meaning 1 vertical on 1½ horizontal. It is unfortunate that an engineering requirement is expressed by two different methods in such a conflicting order and care must be taken to understand which expression is used.

TABLE 11.—STABLE CUT AND FILL SLOPES

Material	Climatic Conditions					
	Combined Rain and Heavy Frost		Rain but Not Much Frost		Arid Regions Not Much Frost	
	Cut	Fill	Cut	Fill	Cut	Fill
Sand	1½ : 1 2 : 1	1½ : 1 2 : 1	1½ : 1 2 : 1	1½ : 1 2 : 1	2 : 1 4 : 1	2 : 1 4 : 1
Gravel	1½ : 1	1½ : 1	1½ : 1 1 : 1	1½ : 1	1½ : 1 1 : 1	1½ : 1
Loam	1½ : 1	1½ : 1	1½ : 1	1½ : 1	1¼ : 1	1½ : 1
Clay	1½ : 1 2 : 1	1½ : 1 4 : 1	1 : 1	1½ : 1 3 : 1	1 : 1 ¾ : 1	1½ : 1
Boulders and earth	1½ : 1	1½ : 1	1 : 1	1½ : 1	1 : 1	1½ : 1
Large rock slabs extending back into hill and earth	1 : 1	1½ : 1	¾ : 1	1½ : 1	¾ : 1	1½ : 1
Disintegrated rock	½ : 1	1½ : 1	½ : 1	1½ : 1	½ : 1	1¼ : 1
Solid rock	¼ : 1	1 : 1	¼ : 1	1 : 1	¼ : 1	1 : 1

Discussion of Pavement Widths and Effect on Cost.—Table 12 shows the approximate cost of different types of hard pavements per mile per foot of width. These costs and all other comparative costs in the book are based on labor and material prices similar to those prevailing in 1912 to 1914. Labor approximately $0.20 per hour. Cement approximately $1.25 per bbl. net, etc. The table is intended to illustrate only the comparative effect of width on cost.

TABLE 12

Pavement	Cost per Foot Width per Mile
Brick	$1200
Asphalt	1100
Concrete	950
Bituminous Macadam	750
Waterbound Macadam	650

The difference of even a foot in width makes a large difference in cost where it is applied to a State system and the question of the most suitable width is open to argument. There are two sets in general use 10′, 12′, 15′ and 18′; and 12′, 14′, 16′ and 20′. The first seems the most logical using the 10′ and 12′ widths with special shoulder treatment on feeder roads (Class III); the 15′ width with stone or gravel shoulders for macadam construction on secondary roads (Class II) and the 18′ width for rigid pavements on the Class I Traffic roads. (For Classification of Traffic, see page 164.)

There are two ways of approaching the problem. The first is to build the strong metaling just wide enough to comfortable take the heavy traffic and if the natural shoulder material is not suitable treat the shoulders to a width of from 16′ to 22′ with gravel, crusher run or 2½″ stone filled and rolled or if desired puddled or tarred making them suitable and wide enough for the turn out traffic. Referring to the widths actually used by hard traffic previously discussed this method results in the 12′ and 15′ widths. The second way is to make the full depth of metaling just wide enough to allow traffic to pass by careful driving not giving the shoulders any special treatment. This method results in the 14′ width on unimportant roads. The 16′ width is harder to justify as on the main roads it is wider than necessary for heavy travel and too narrow for automobile "turn out traffic." Where rigid pavements are needed 18′ is the minimum width recommended as dangerous ruts develop along the edges where the 15′ or 16′ width is used and even with careful maintenance this condition can not be avoided under heavy truck traffic.

While shoulder treatment is desirable on the main traveled roads its importance on side roads should not be overestimated. A record of a trip from Albany to Binghampton, New York, showed

that rigs were passed on an average once every 4 miles outside of villages. From this it would seem that for secondary roads of this character shoulder treatment is not worth while even for the 12′ width unless particularly bad soil conditions are encountered. Where the 10′ width is used solid turnouts should be provided at frequent intervals to allow heavily loaded vehicles to pass.

In the writer's opinion 10′ or 12′ should be used in preference to 14′ on side roads where the shoulder material is good or where gravel is cheap or local crushed stone is used in construction making it possible to obtain a cheap crusher run and that 14′ should be used where the shoulder material is poor and where gravel or imported stone is costly. On the main roads a 15′ macadam is as satisfactory as the 16′ width and is cheaper under all conditions as the 16′ width does not overcome the necessity for a good shoulder. Where rigid pavements are required 18′ is the minimum width that will give satisfaction on double track roads.

Examples of typical stone distribution and grading widths are given below and plates showing current practice in different parts of the United States follow.

Examples of Typical Sections.—The following sketches show a number of variations in grading shapes and stone widths and distribution for bituminous macadams which are applicable to special conditions.

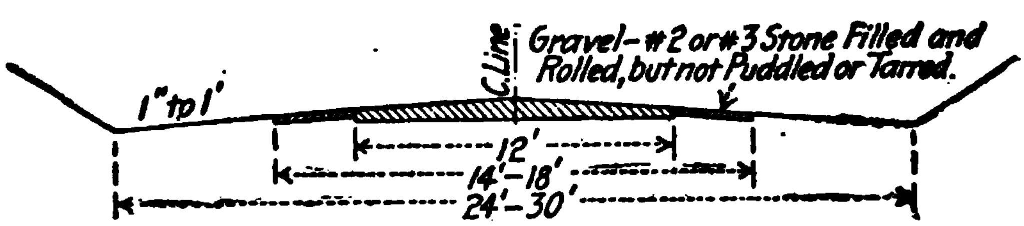
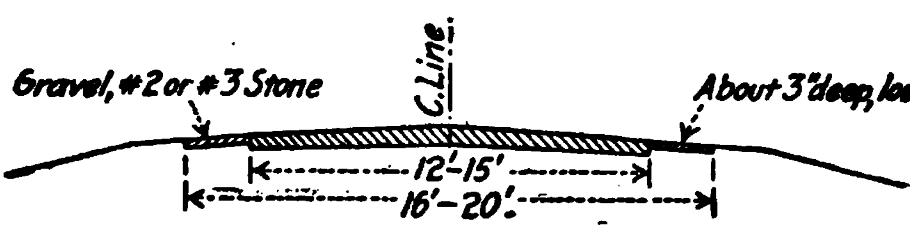
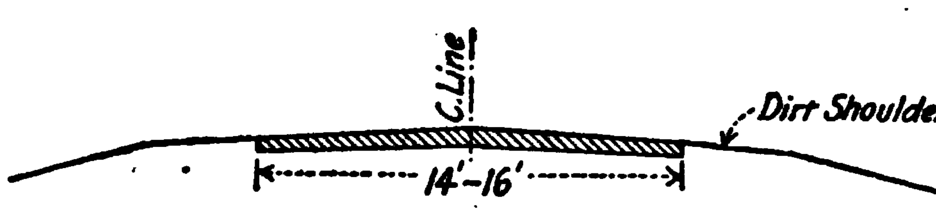


FIG. 7.—Bituminous macadam.



Shoulder treatment.



No shoulder treatment.

Figures 7, 7A and 7B show the stone distribution with and without shoulder treatment for secondary and main roads.

Figure 8 shows a good typical grading section for ordinary conditions on a main road.

Figure 9 shows a typical grading section where a small amount

of water is expected. If for any reason it is not practicable to cut into the hill beyond a certain depth and more dirt is needed for fill than is given by the 26′ section at this depth the shoulders can be widened, provided the tops of the slopes keep within the right-of-way. It is always best to use as shallow a ditch as possible as it simplifies the construction and maintenance of entrances to the abutting properties.

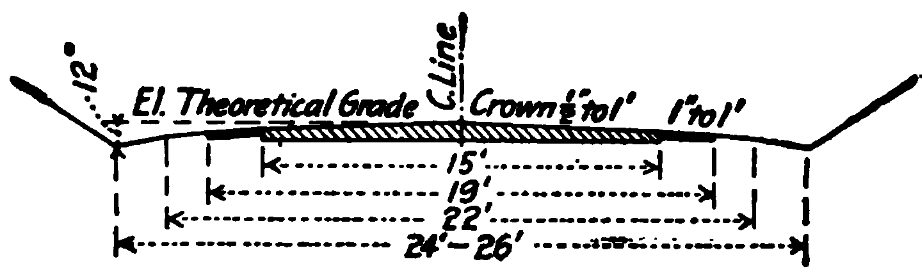


FIG. 8.—Bituminous macadam.

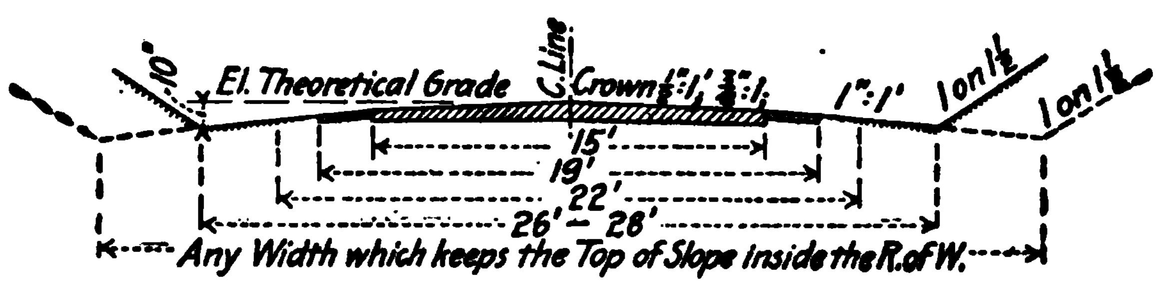


FIG. 9.

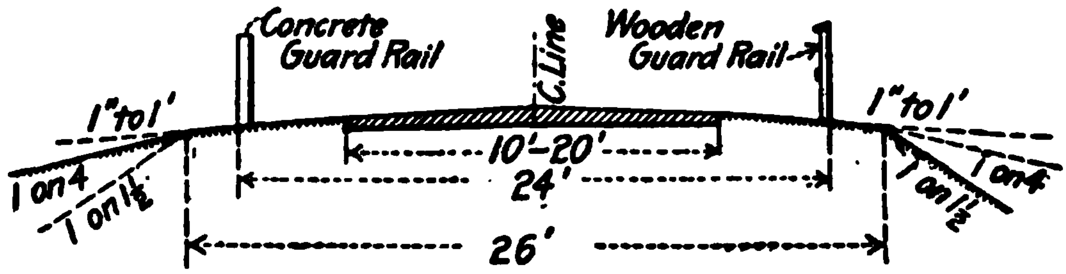


FIG. 10.

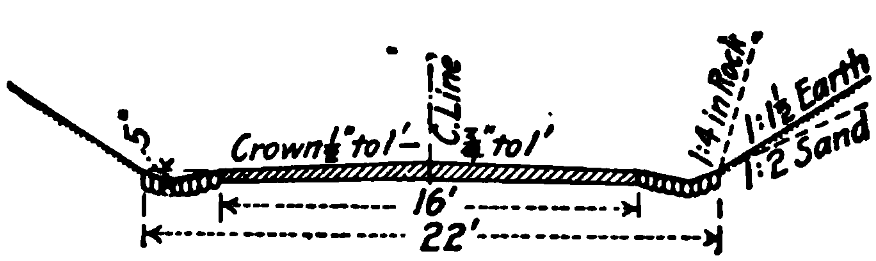


FIG. 11.

Figure 10 gives a section showing the variations in fill. A slope of 1″ to 1′ beyond the 22′ width is used on shallow fills. An embankment slope of 4 to 1 is used for ordinary fills up to 7′ depth; beyond a 7′ depth it is cheaper to erect and maintain guard rail using a 1½ to 1 embankment slope. The cost of guard rail is taken up under Minor Points.

The section shown in Figure 11 is used for unusually heavy cuts to keep the excavation as low as possible. If used on a sharp

curve it should be widened, "banked" and "Daylighted" as indicated in Figures 12 and 4 to increase safety of traffic.

Figure 12 shows a section well suited for sharp curves. The slope of ¾" to 1' is not objectionable for slow traffic on macadam and makes easier riding for rapidly moving vehicles; it also decreases maintenance cost on macadam construction on sharp curves. The macadam should be widened on the inside of the curve as shown in

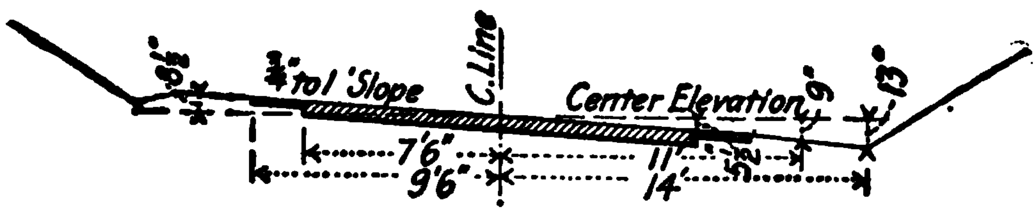


FIG. 12.—Banked section in excavation.

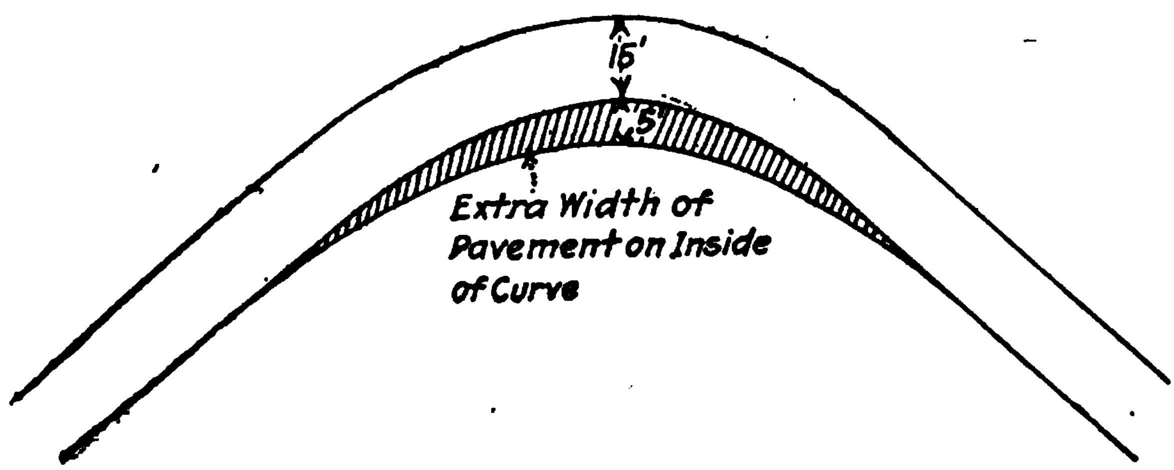


Figure 12A. The superelevation on the curve is obtained by gradually raising the outside edge; the center line elevation and inner edge remain normal. The full superelevation is carried around the entire length of the curve from *PC* to *PT* and reduced to the normal crown at about 150 feet away from the curve ends. Variation in superelevation for curves of different radii is a useless refinement and good practice rarely adopts superelevation for

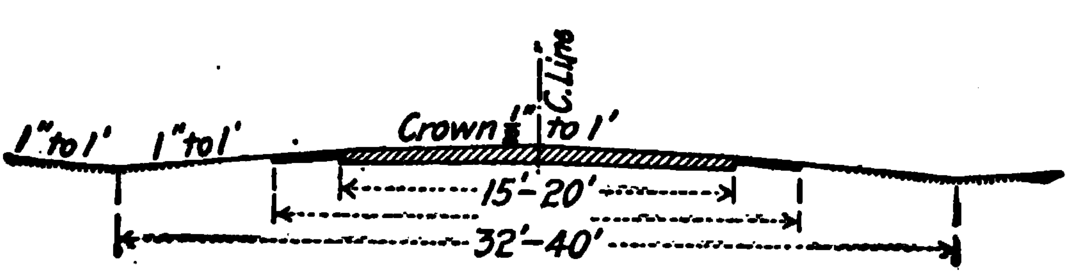


FIG. 13.

radii greater than 800'. The maximum superelevation is generally used for all curves of 500' radii or less and is considered to be limited to 1" per 1' for macadams and ⅝" per foot for rigid pavements. The author prefers ¾" to 1' and ½" to 1' for these types.

Figure 13 is a satisfactory village section and by the use of a variable width will fit conditions on most streets.

The preceding discussion attempts to cover only the main points for every road presents local conditions peculiar to itself that re-

quire special solutions. However, if the Engineer keeps these points in mind he will make an economical and appropriate design.

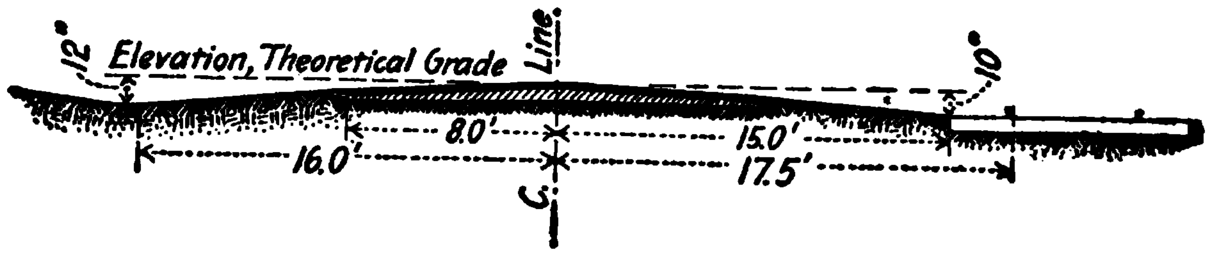
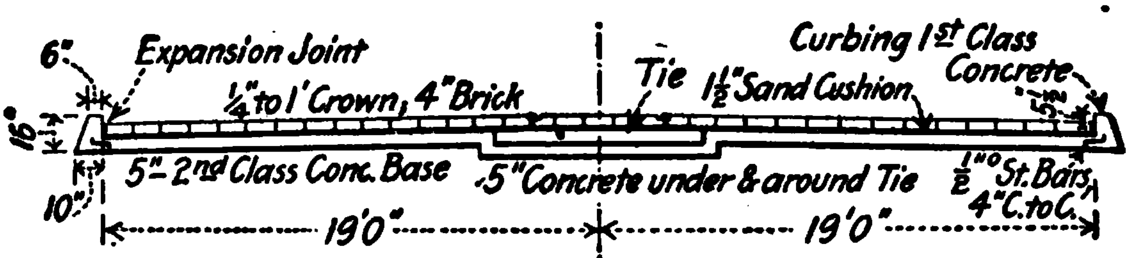


FIG. 14.—Bituminous macadam tracks on side.



Village street, brick pavement. Tracks in center, "T"-rail special grooved brick.

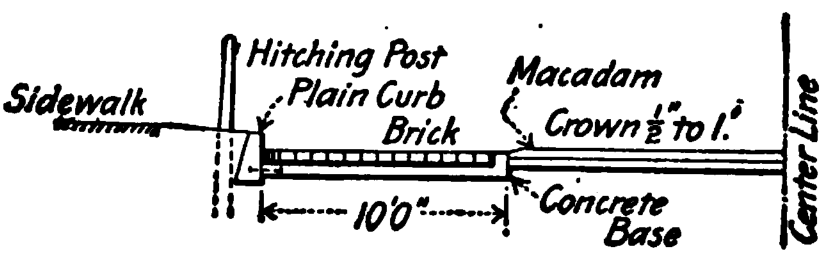


FIG. 15.—Village section. Combined brick and macadam section in front of stores, where horses will be hitched close to the curb. Prevents pawing up the macadam.

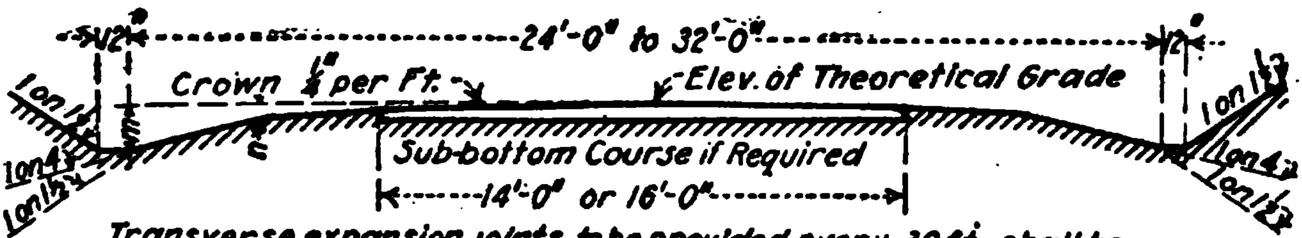
PLATES

The following plates show current practice in standard hard surfaced road sections and serve to strengthen the points brought out in the discussion although they may not comply with all the desirable requirements.

PLATE 1.—New York.
PLATE 2.—California.
PLATE 3.—Massachusetts.
PLATE 4.—Maine.
PLATE 5.—Wyoming.
PLATE 6.—Washington.
PLATE 7.—New Jersey.
PLATE 8.—W. Virginia.
PLATE 9.—Iowa.
PLATE 10.—Pennsylvania.

Plate 1.—New York State 1915 Standards.

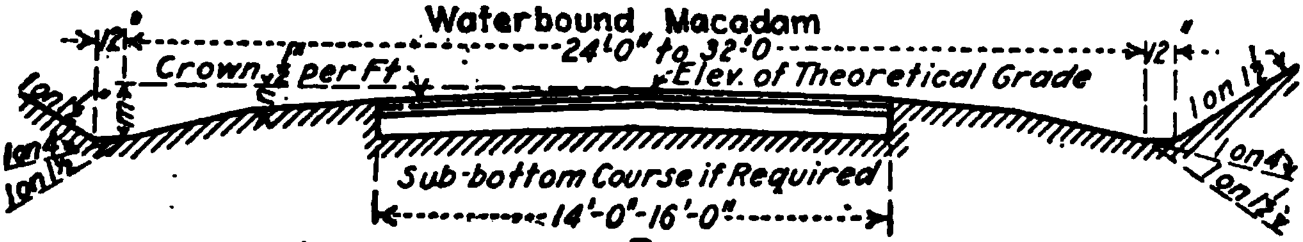
Cement Concrete



Transverse expansion joints, to be provided every 30 ft., shall be composed of a creosoted, yellow pine or tar paper strip ⅜" thick, conforming to the cross section of roadway. Each strip may be composed of two pieces of equal length, butt jointed and fastened together with approved splice piece of No. 26 Iron.

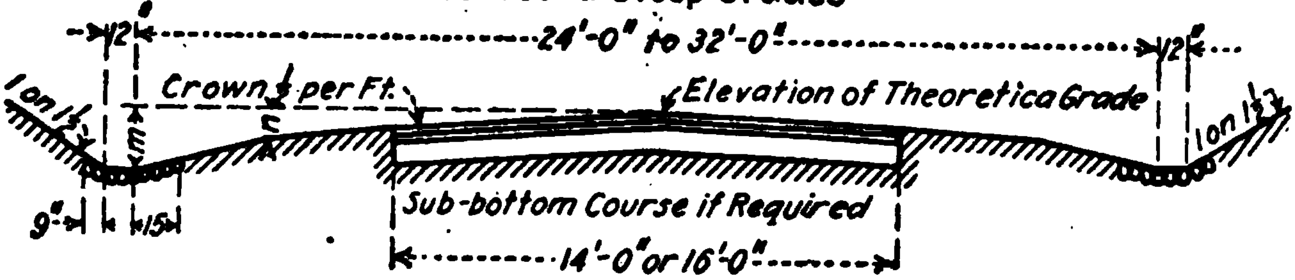
A

Waterbound Macadam



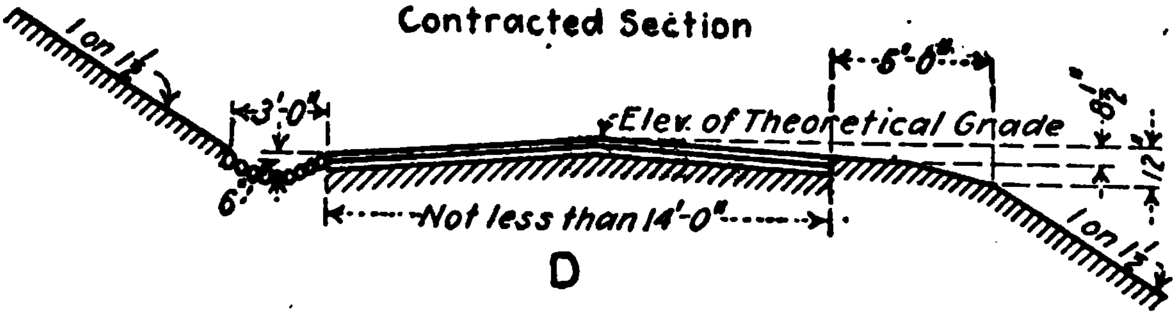
B

Waterbound Steep Grades



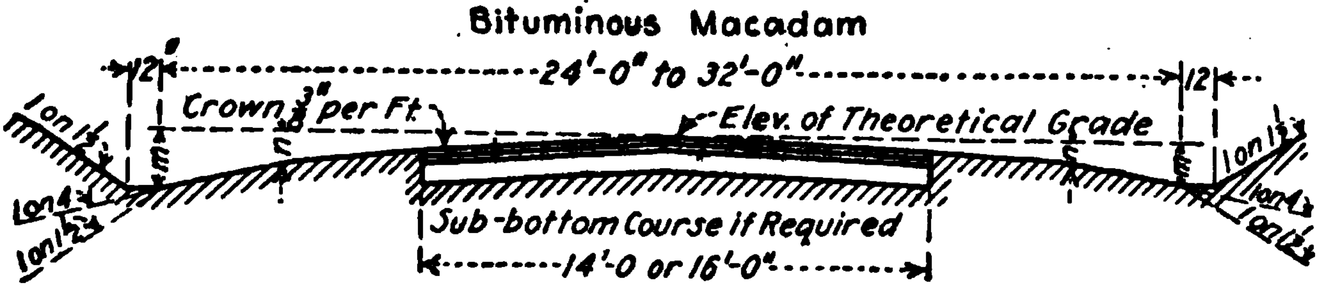
C

Contracted Section



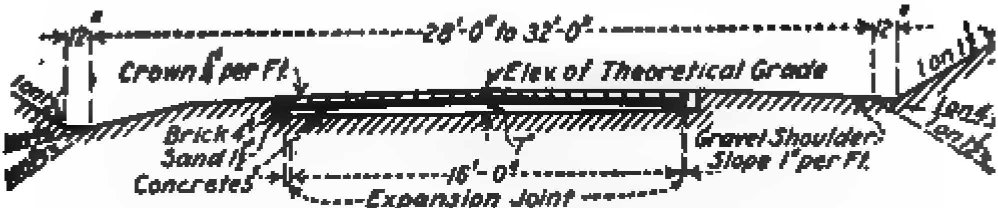
D

Bituminous Macadam



E

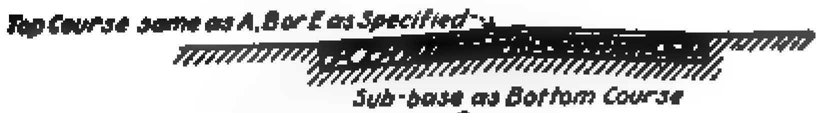
PLATE I.—(*Continued*)



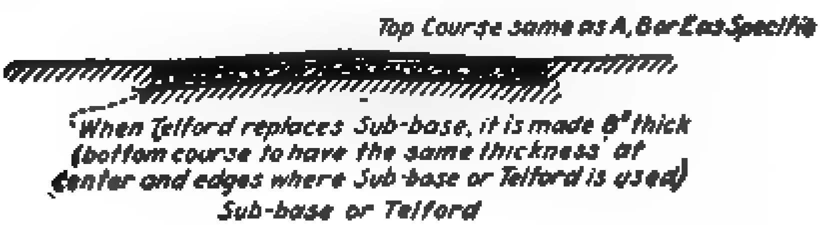
Expansion joints, if of poured type shall be 1" thick. For premoulded type they shall be ½" for 16' width, ¾" for 20' to 24' width and ⅞" for 32' width.

Half Section
F-1

Half Section
F-2



G



H

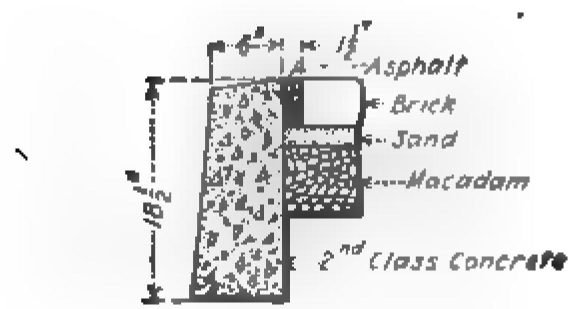


PLATE 1.—(*Continued*)

Typical Section "A"					
Shoulder	Width of Road Metal				Crown ¼" per Ft.
	14 Ft.		16 Ft.		
	"n"	"m"	"n"	"m"	
5 ft.	4¼"	11¾"	4½"	12"	
6 ft.	4¾"	13¾"	5"	14"	
7 ft.	5¼"	15¾"	5½"	16"	
8 ft.	5¾"	17¾"	6"	18"	

Typical Section "B"					
Shoulder	Width of Macadam				Crown ⅓" per Ft.
	14 Ft.		16 Ft.		
	"n"	"m"	"n"	"m"	
5 ft.	6"	13⅓"	6⅓"	14"	
6 ft.	6⅓"	15⅓"	7"	16"	
7 ft.	7"	17⅓"	7⅓"	18"	
8 ft.	7⅓"	19⅓"	8"	20"	

Typical Section "E"					
Shoulder	Width of Macadam				Crown ⅜" per Ft.
	14 Ft.		E 16 Ft.		
	"n"	"m"	"n"	"m"	
5 ft.	4½"	12"	4⅞"	12⅞"	
6 ft.	4⅞"	13⅞"	5¼"	14¼"	
7 ft.	5¼"	15¾"	5⅝"	16⅝"	
8 ft.	5⅝"	17⅝"	6"	18"	

Typical Sections "F-1" and "F-2"				
Shoulder	Width of Brick 16 Ft.			Crown ¼" per Ft.
	F-1		F-2	
	"n"	"m"	"n"	
5 ft.				
6 ft.	4¼"	13¼"	8"	
7 ft.	4⅝"	15⅛"	9"	
8 ft.	5"	17"	10"	

NOTE. "n" = difference in elevation between center of road and center of shoulder.
"m" = " " " " " " " " ditch.

Difference in elevation given in tables are measured from theoretical grade.

NOTE. { For widths of 20′ or less provide an expansion joint 1" wide on each side.
" " 20′ to 30′ " " " " " 1¼" " " " "
" " 30′ to 40′ " " " " " 1½" " " " "

Plate 2.— California Standards.

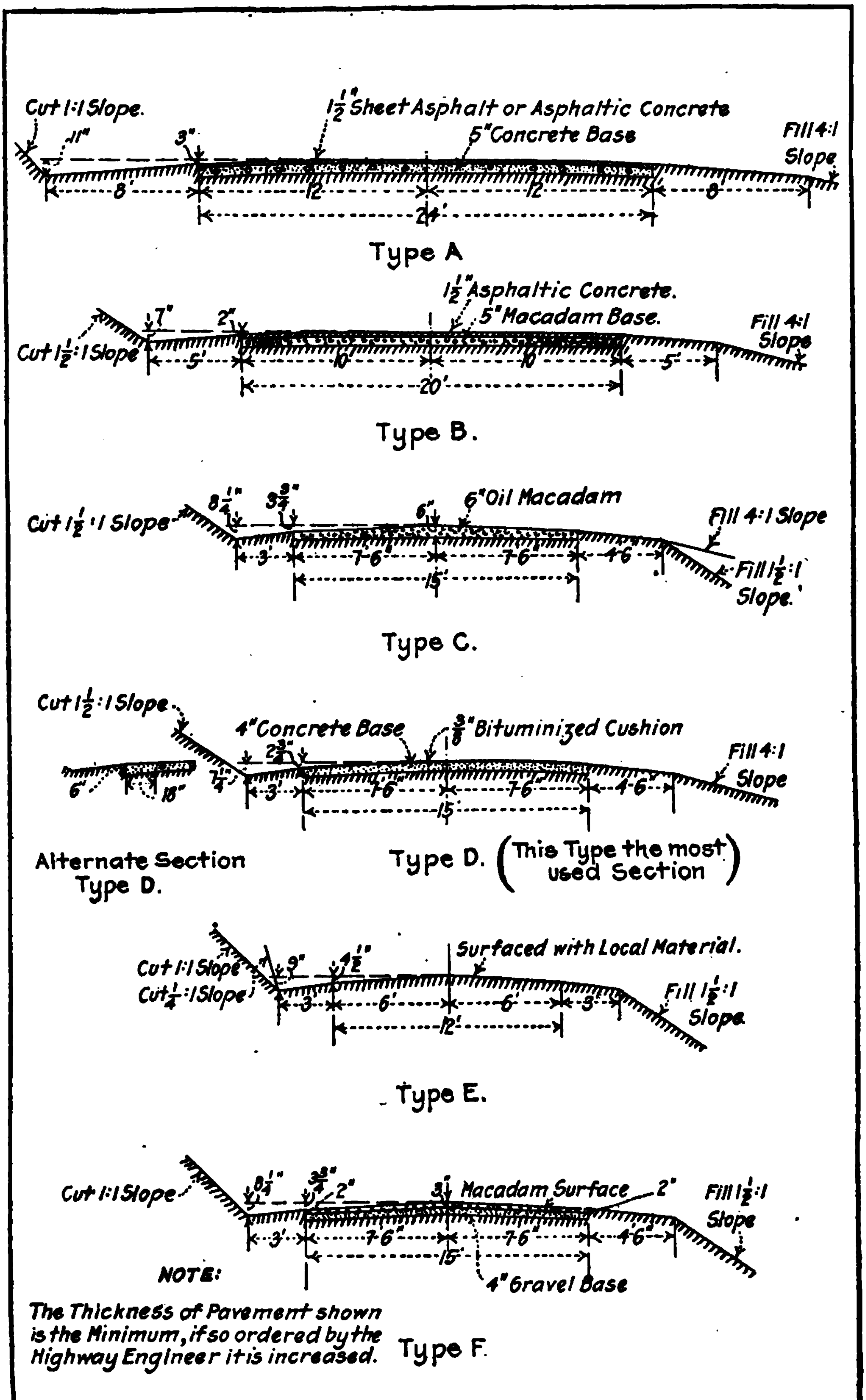
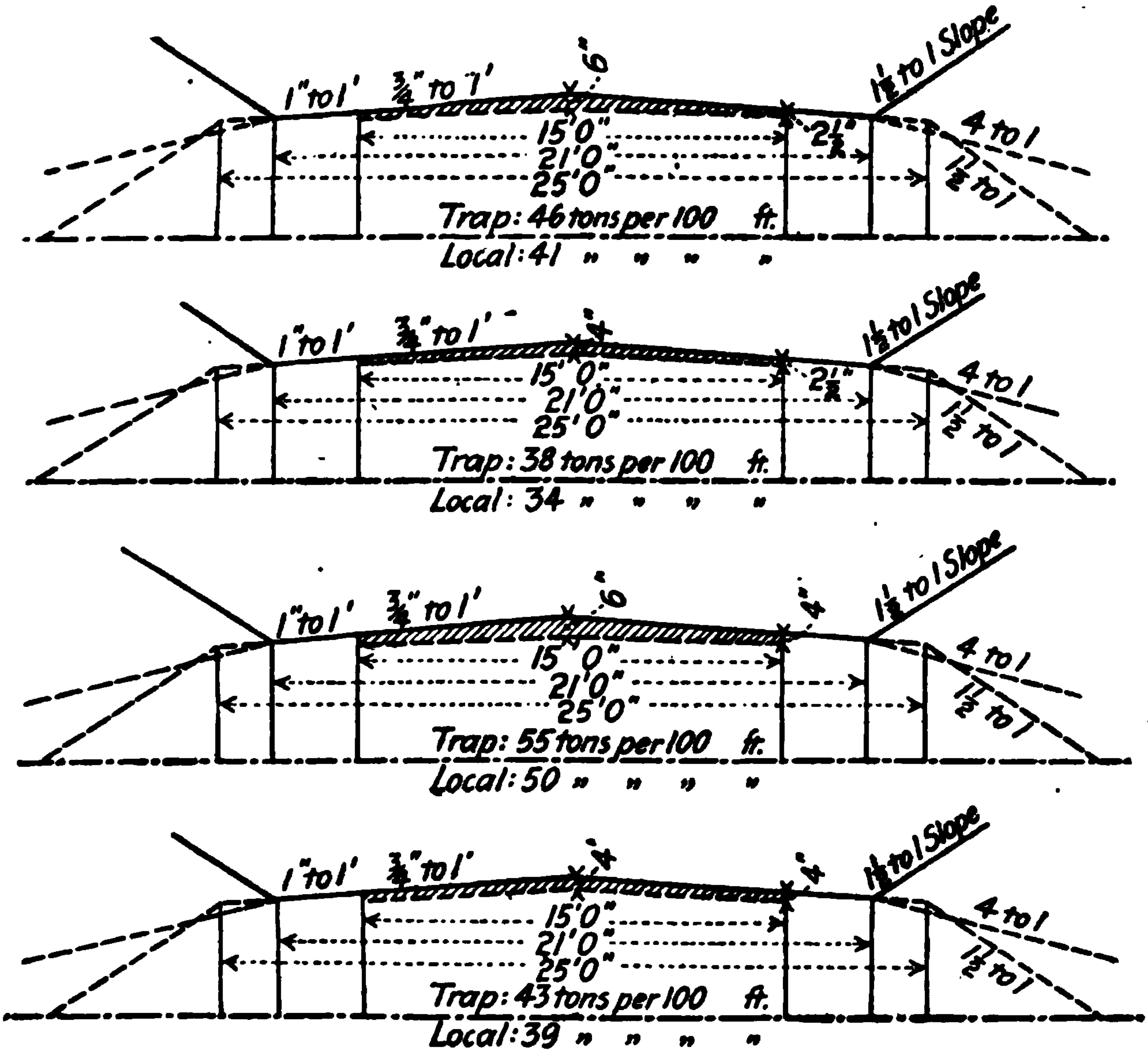
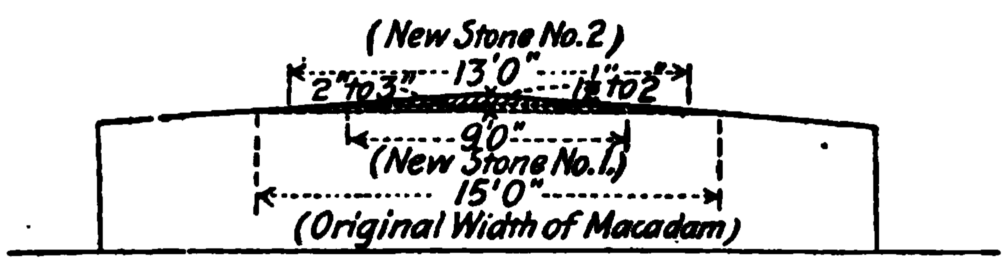
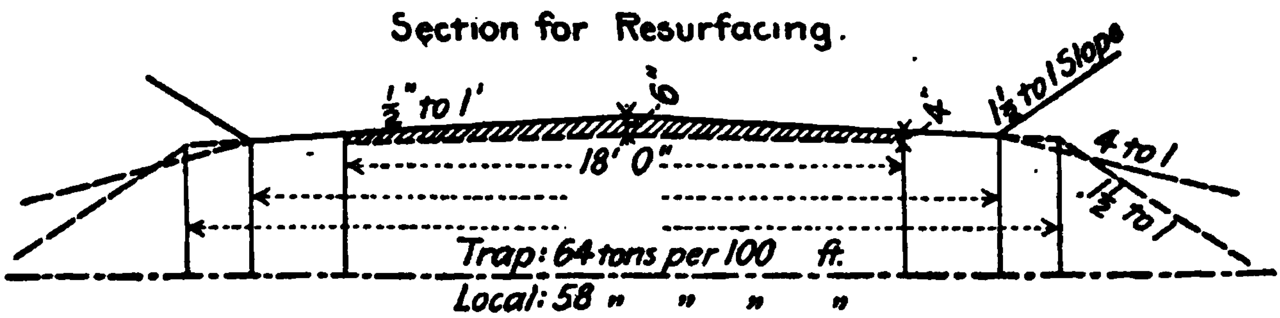


PLATE 3.— MASSACHUSETTS STANDARDS.

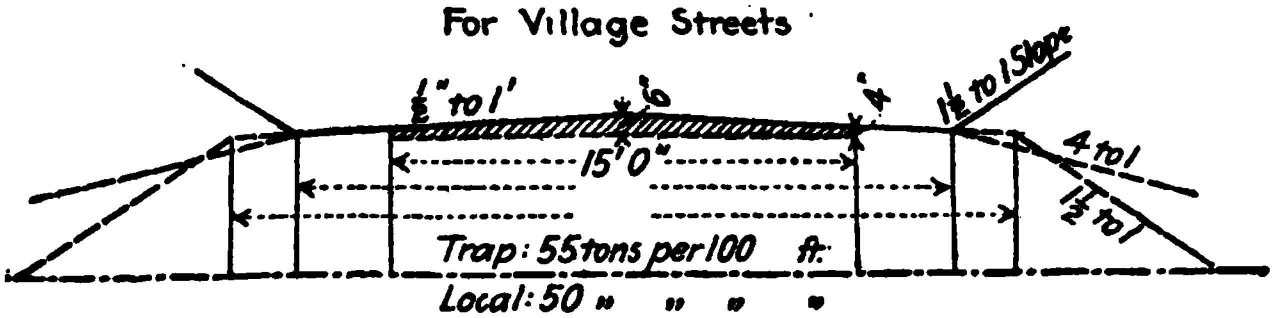




Section for Resurfacing.



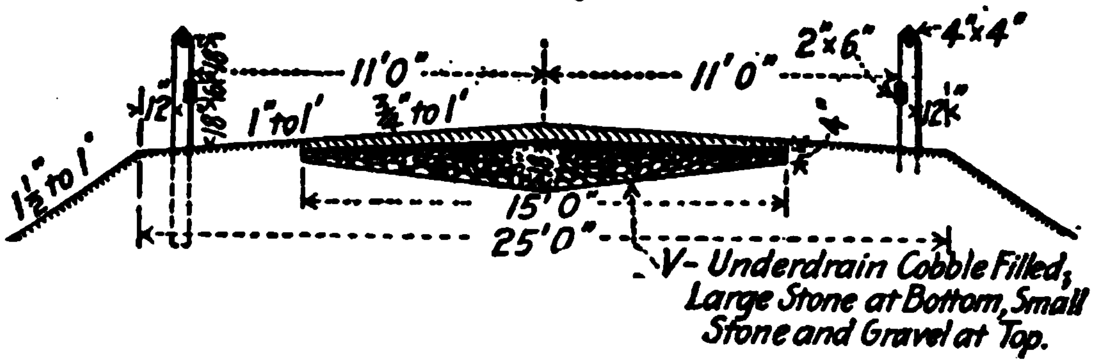
For Village Streets

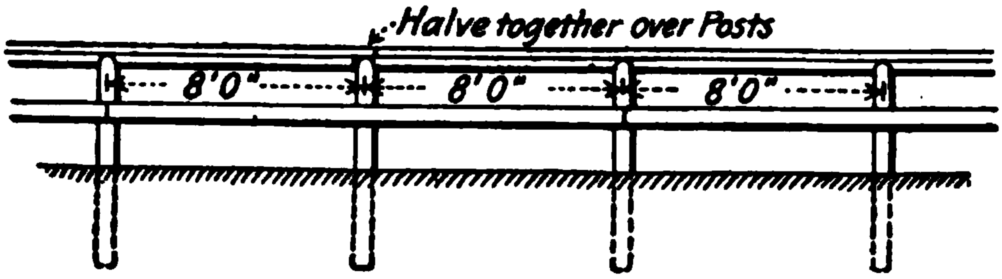


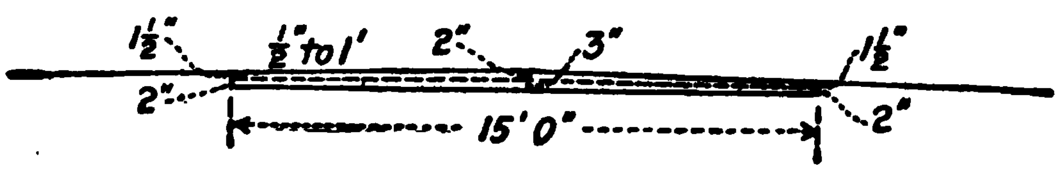
For Village Streets.

PLATE 3.—(*Continued*)

Note: The Backs of Guard-Rail Posts to be set one foot from Edge of Embankment for all Widths.







CONDITION No. 1.—See note below.

Trap Rock—Lower course, No. 1 stone, 24 tons; screenings for binder, 4 tons. Upper course, No. 2 stone, 16 tons.

Local Stone—Lower course, No. 1 stone, 22 tons; screenings for binder, 4 tons. Upper course, No. 2 stone, 14 tons.

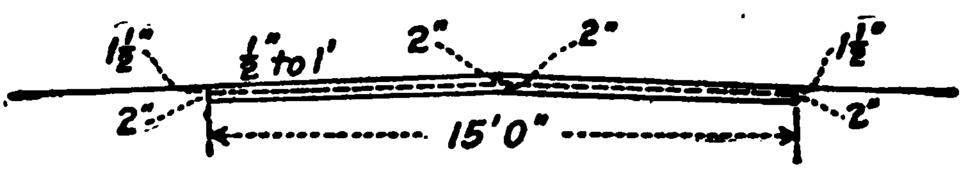
CONDITION No. 2.—See note below.

Trap Rock—Lower course, No. 1 stone, 24 tons Upper course, No 2 stone, 16 tons; screenings for binder, 7 tons.

Local Stone—Lower course, No. 1 stone, 22 tons. Upper course, No. 2 stone, 14 tons; screenings for binder, 7 tons.

Total tonnage per 100': Trap, 47; Local, 43.

NOTE.—For both penetration methods—grouting or the modified Gladwell method—there should be two applications of asphaltic oil, each ¾ gal. per sq. yd. There may be also a third application of ¼ gal. per sq. yd. for surface finish. For surface treatment there should be one application of ½ gal. of oil per sq. yd. or two applications of ¼ gal. each per sq. yd. on the finished surface of the roadway.



CONDITION No. 1.

Trap Rock—Lower course, No. 1 stone, 19 tons; screenings for binder, 3 tons. Upper course, No. 2 stone, 17 tons.

Local stone—Lower course, No. 1 stone, 17 tons; screenings for binder, 3 tons. Upper course, No. 2 stone, 15 tons.

Total tonnage per 100': Trap, 39; Local, 35.

CONDITION No. 2.

Trap Rock—Lower course, No. 1 stone, 19 tons. Upper course, No. 2 stone, 17 tons; screenings for binder, 6 tons.

Local Stone—Lower course, No. 1 stone, 17 tons. Upper course, No. 2 stone, 15 tons; screenings for binder, 6 tons.

Total tonnage per 100': Trap, 42; Local, 38.

NOTE.—Condition No. 1: Bituminous Treatment—Penetration—lower course bound with stone screenings or sand.

Condition No. 2: Bituminous Treatment—Surface Spraying—screenings of sand binder in upper course.

PLATE 4.—MAINE STANDARD SECTIONS.

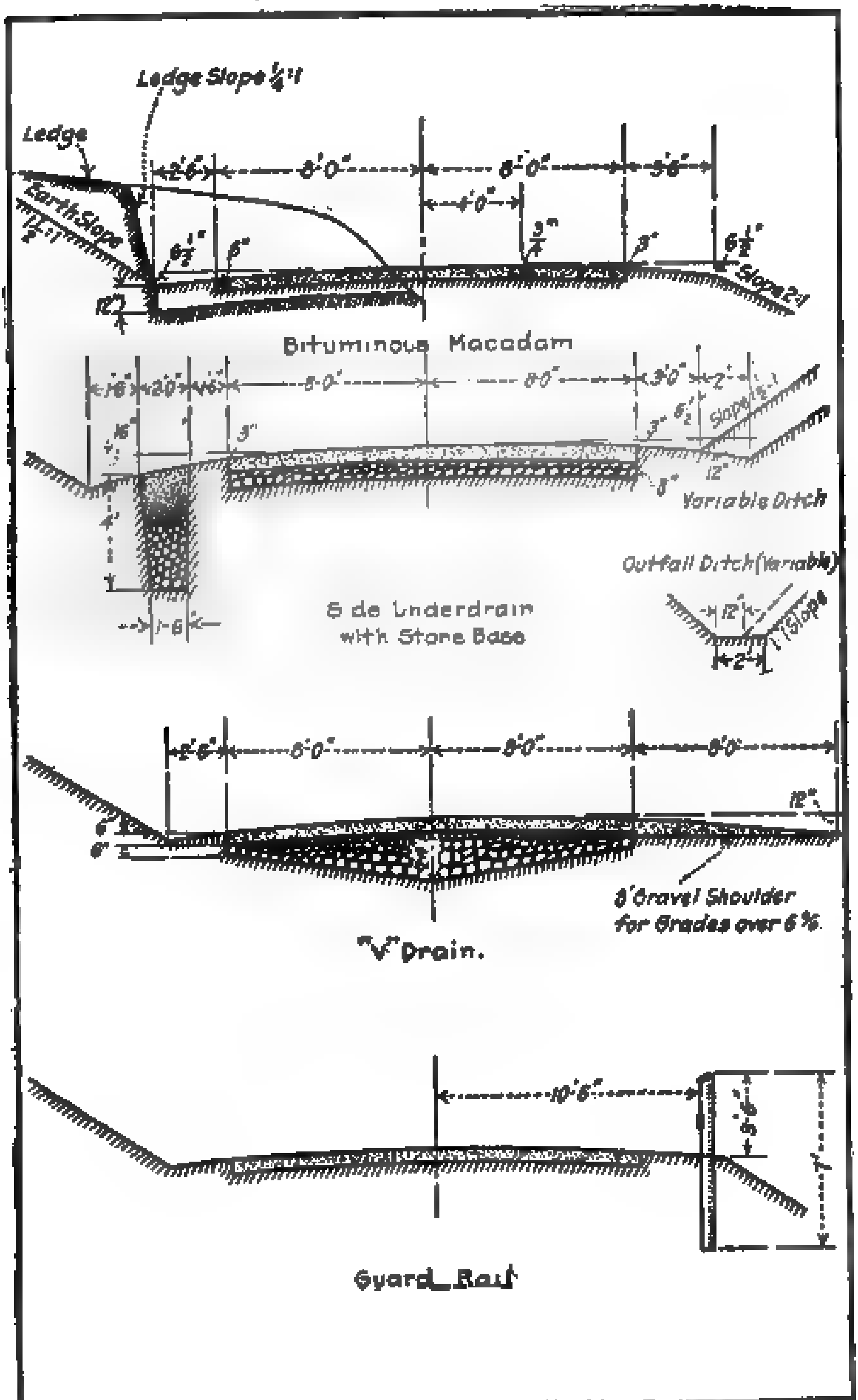


PLATE. 4.—(*Continued*)

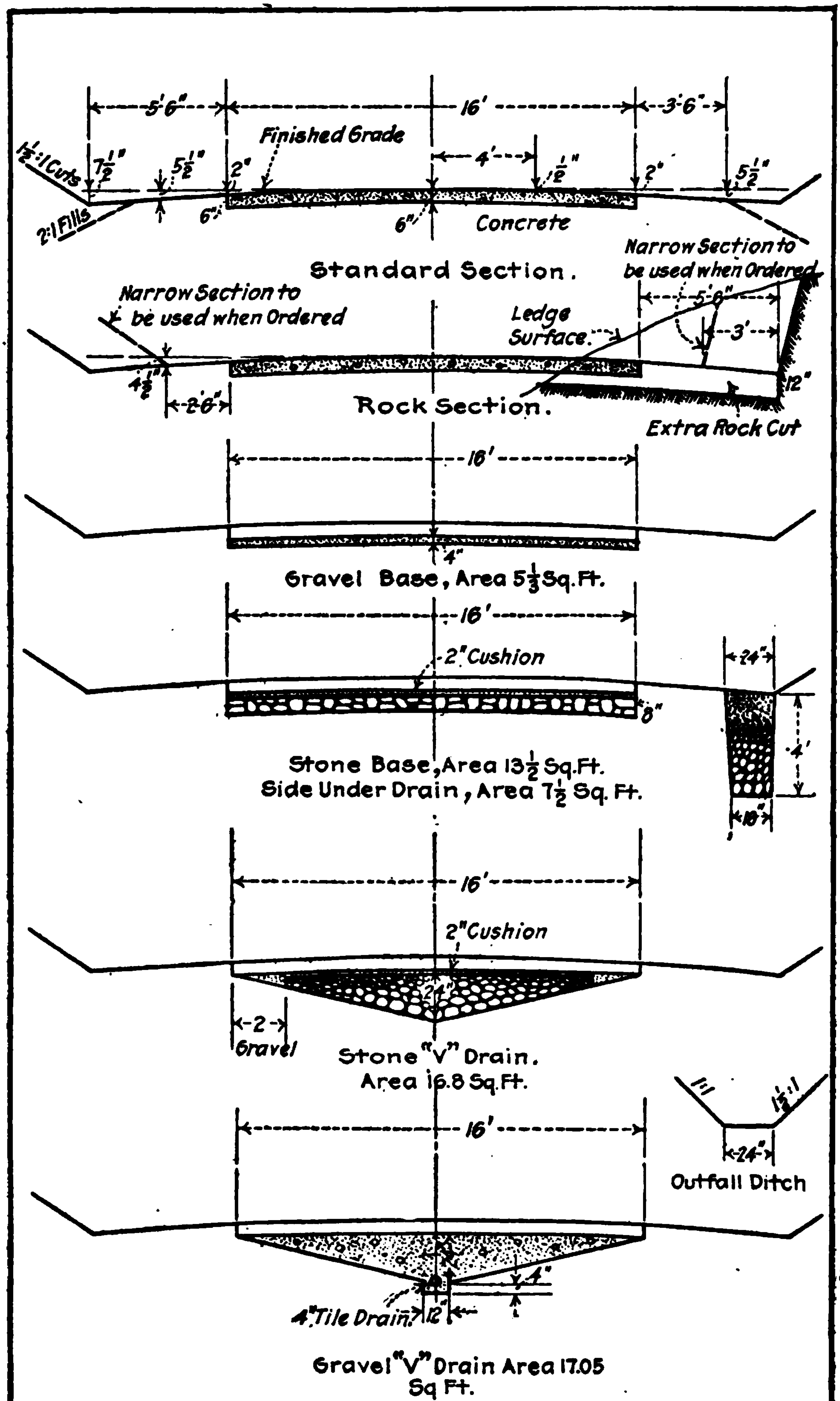


PLATE 5.—WYOMING SECTIONS.

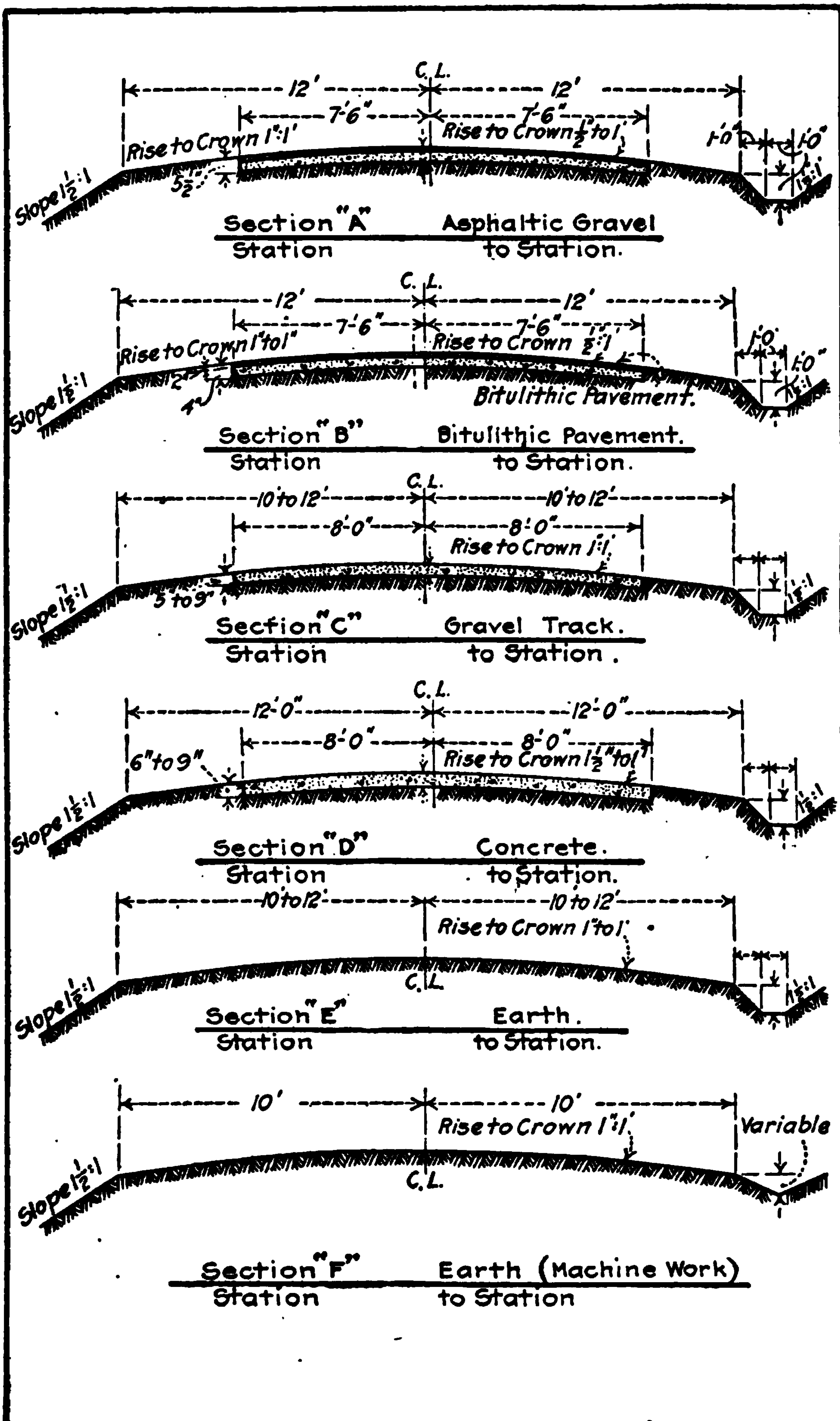


PLATE 6.—STATE OF WASHINGTON TYPICAL SECTIONS.

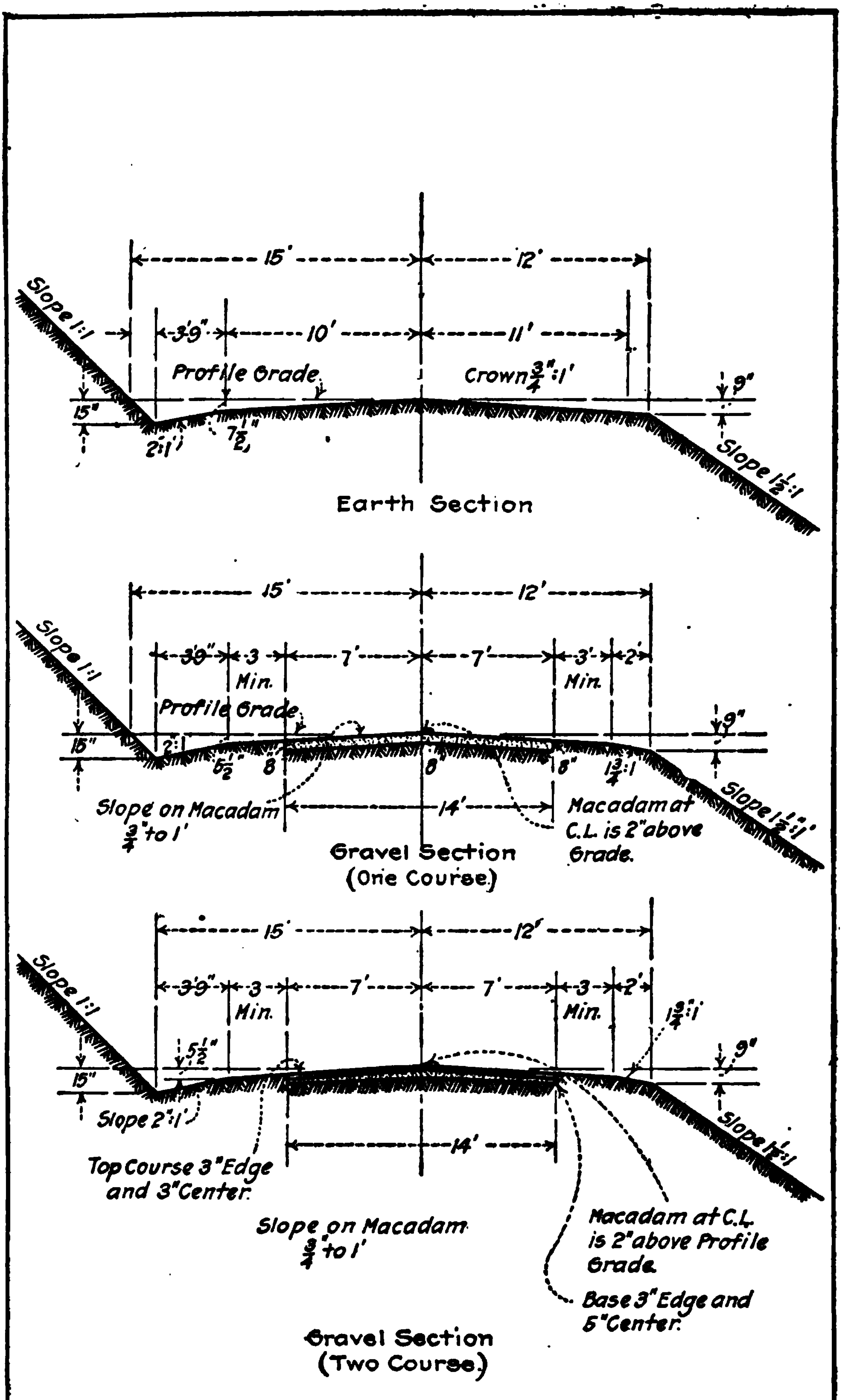


PLATE 6.—(*Continued*)

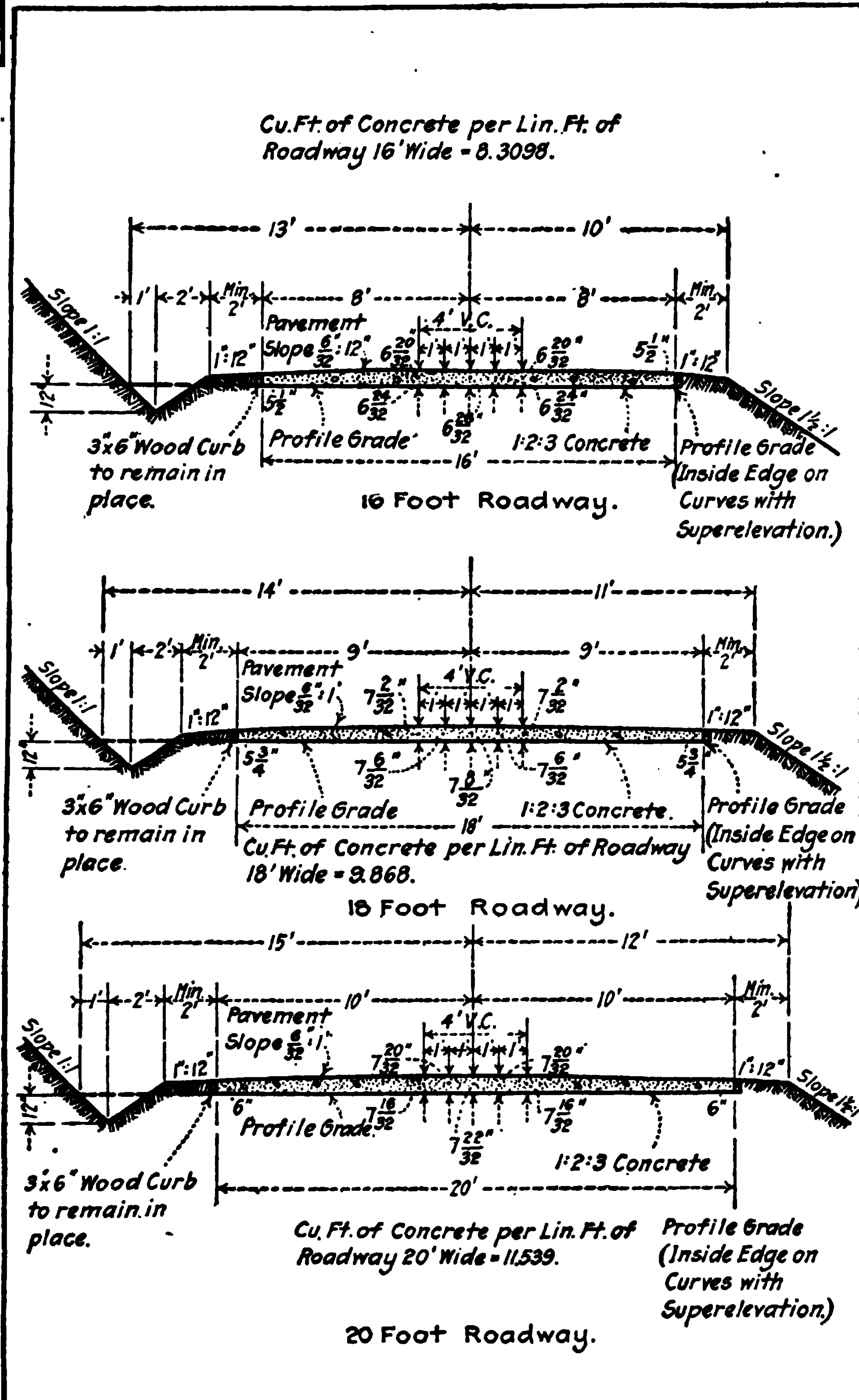


PLATE 7.—WEST VIRGINIA TYPICAL SECTIONS.

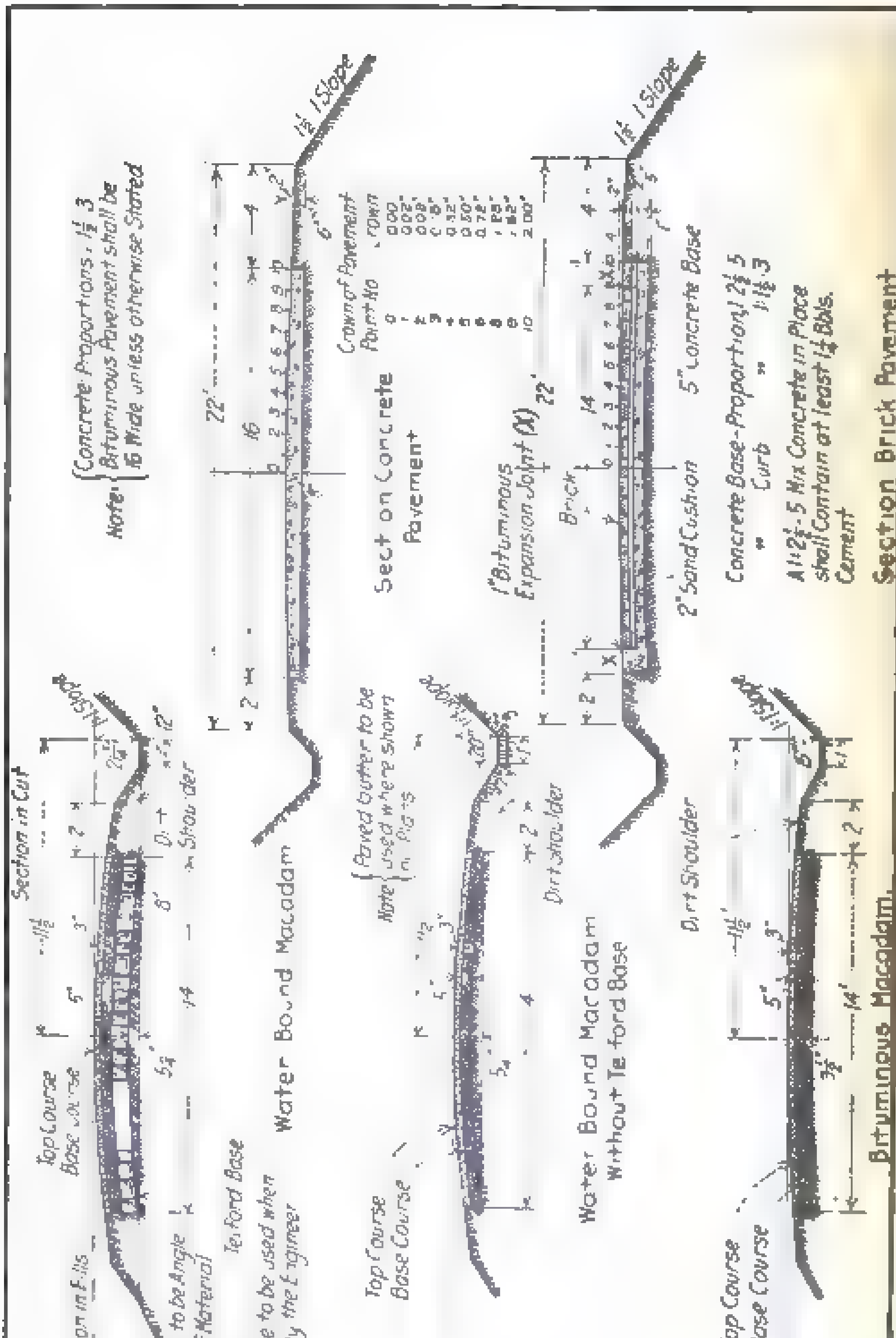


PLATE 7.—(*Continued*)

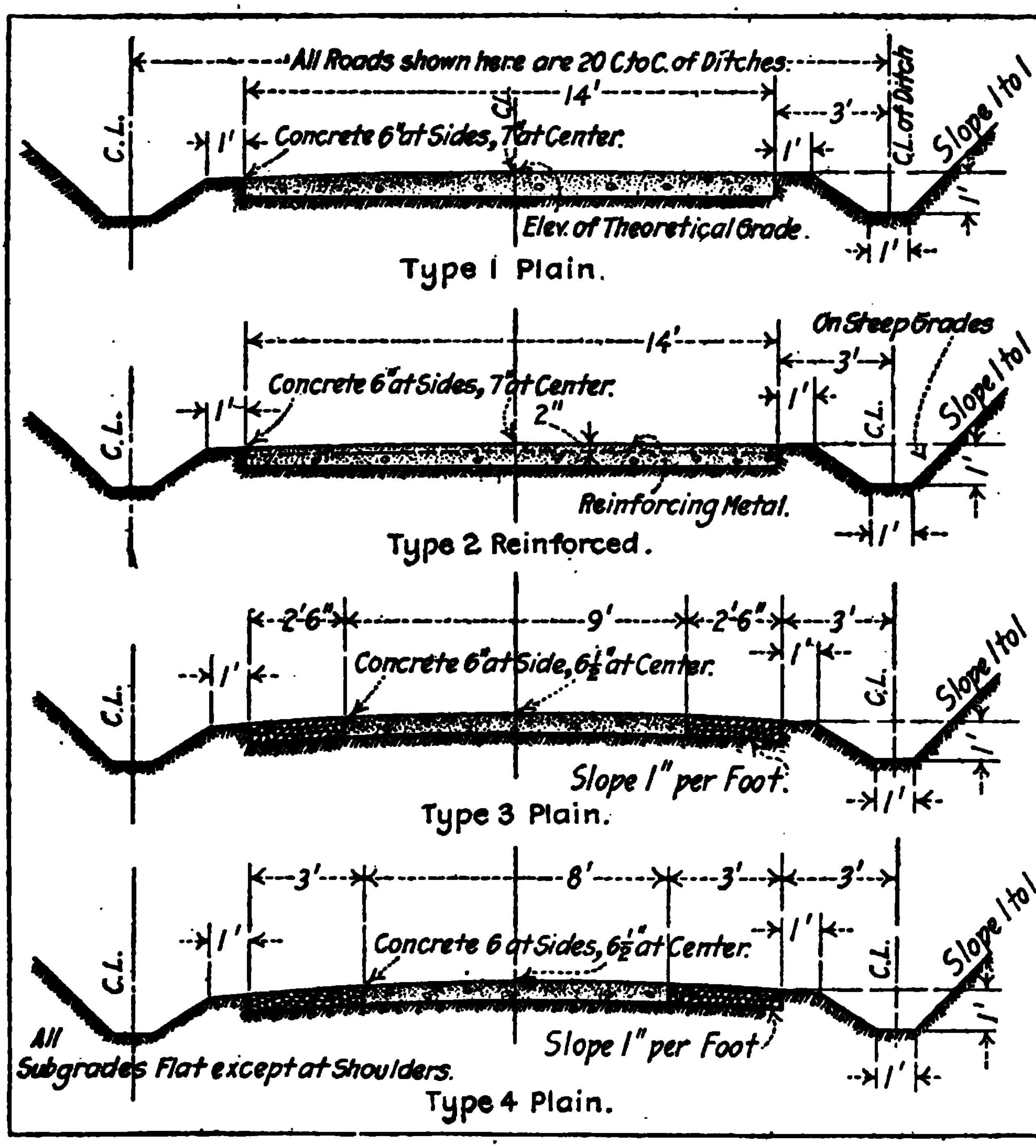
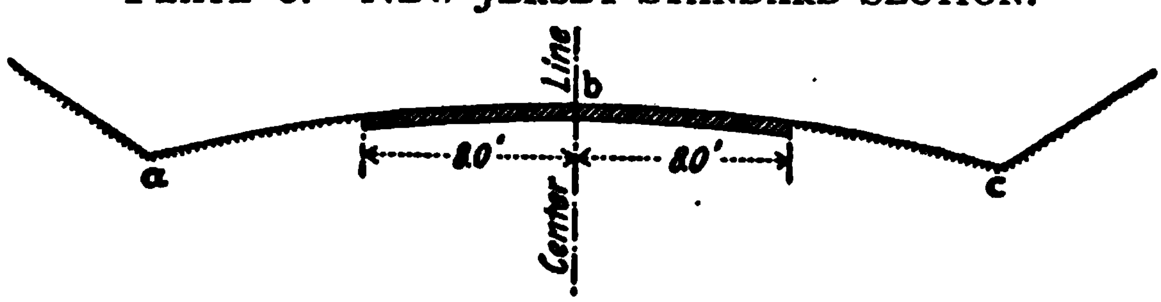


PLATE 8.—NEW JERSEY STANDARD SECTION.



This Section is the Arc of a Circle drawn through the Points
a. b & c
Crown for Waterbound Macadam ¾" to 1.'
" " Bituminous " ½" to 1.

PLATE 9.—IOWA TYPICAL SECTIONS.

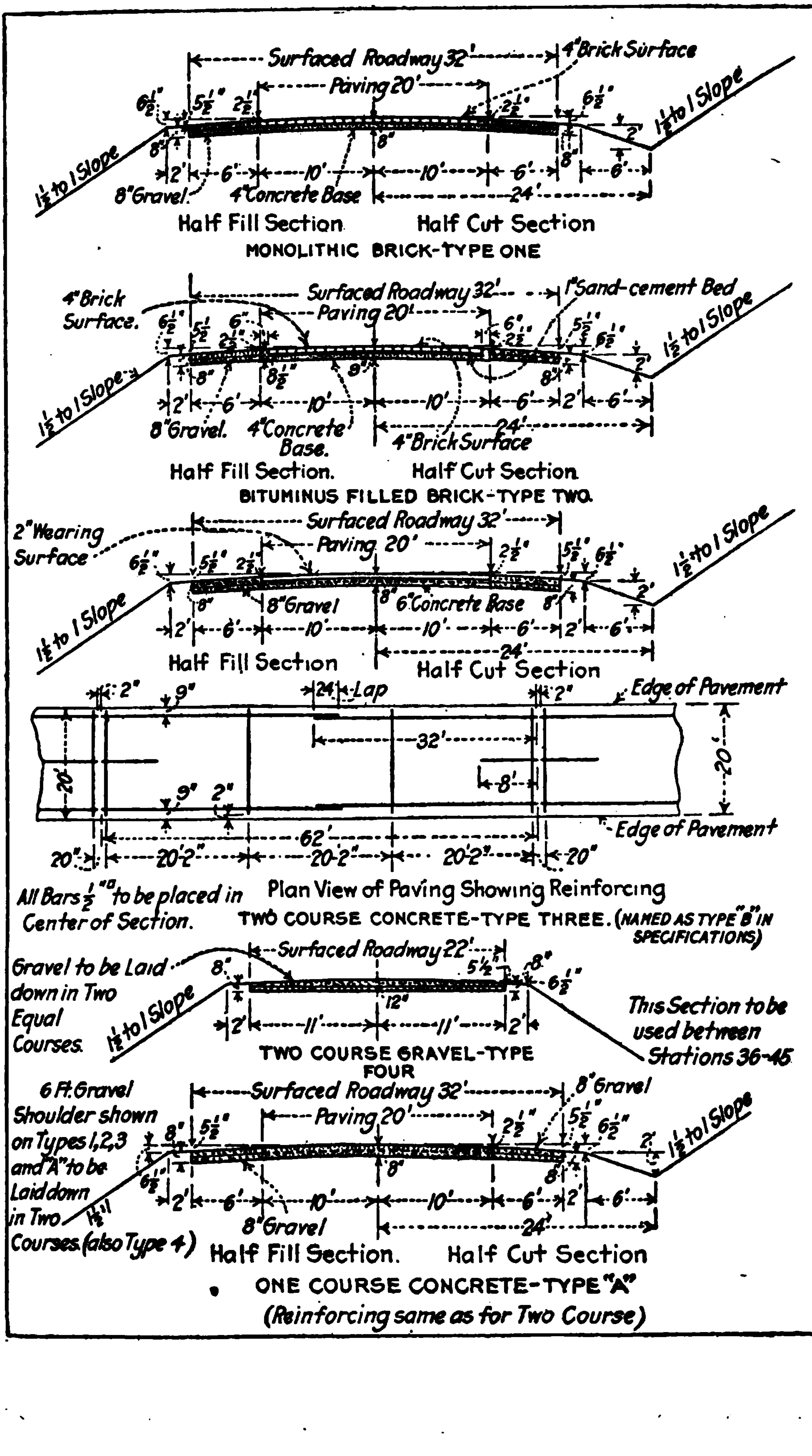


PLATE 10.—STATE OF PENNSYLVANIA TYPICAL SECTIONS.

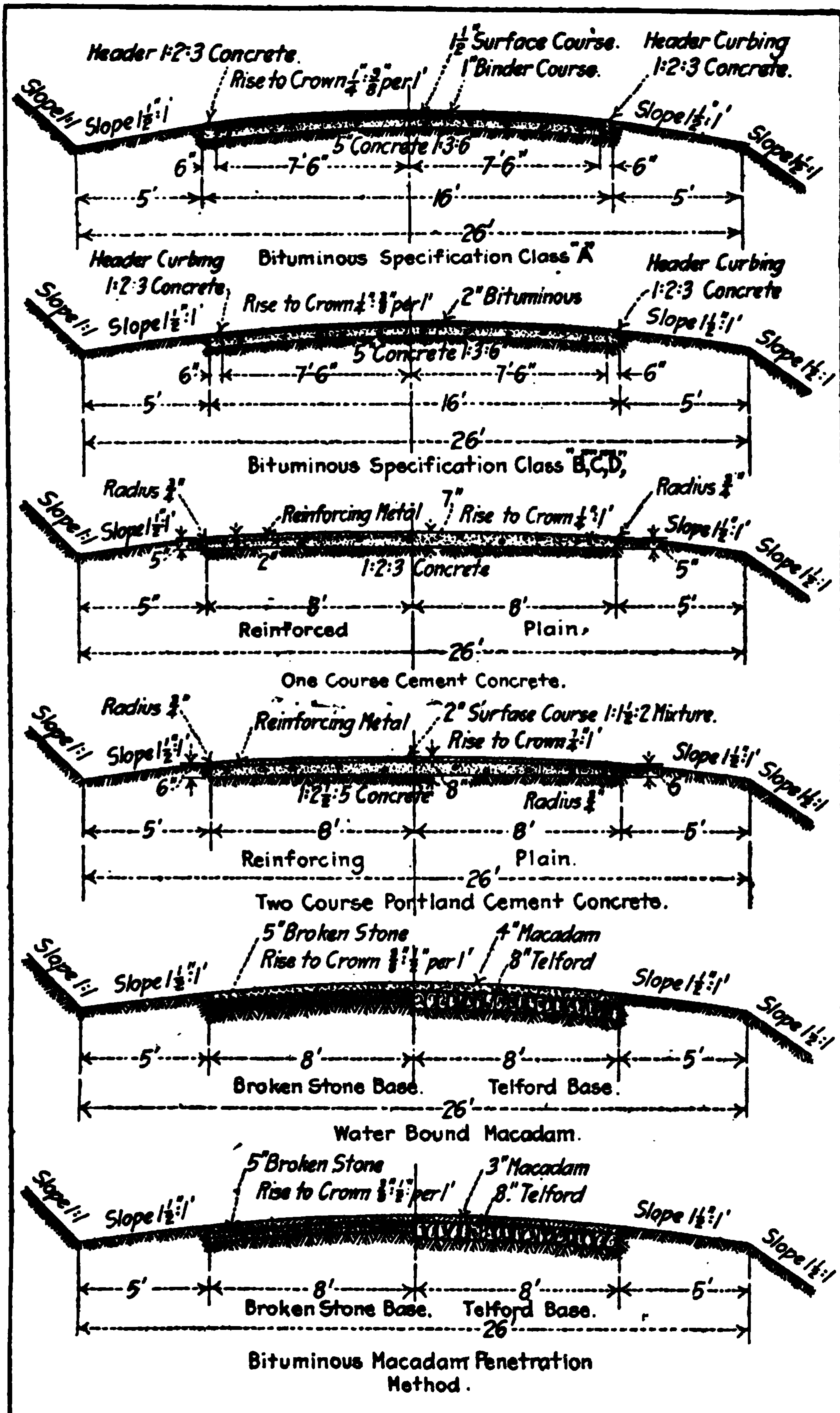


PLATE 10.—(*Continued*)

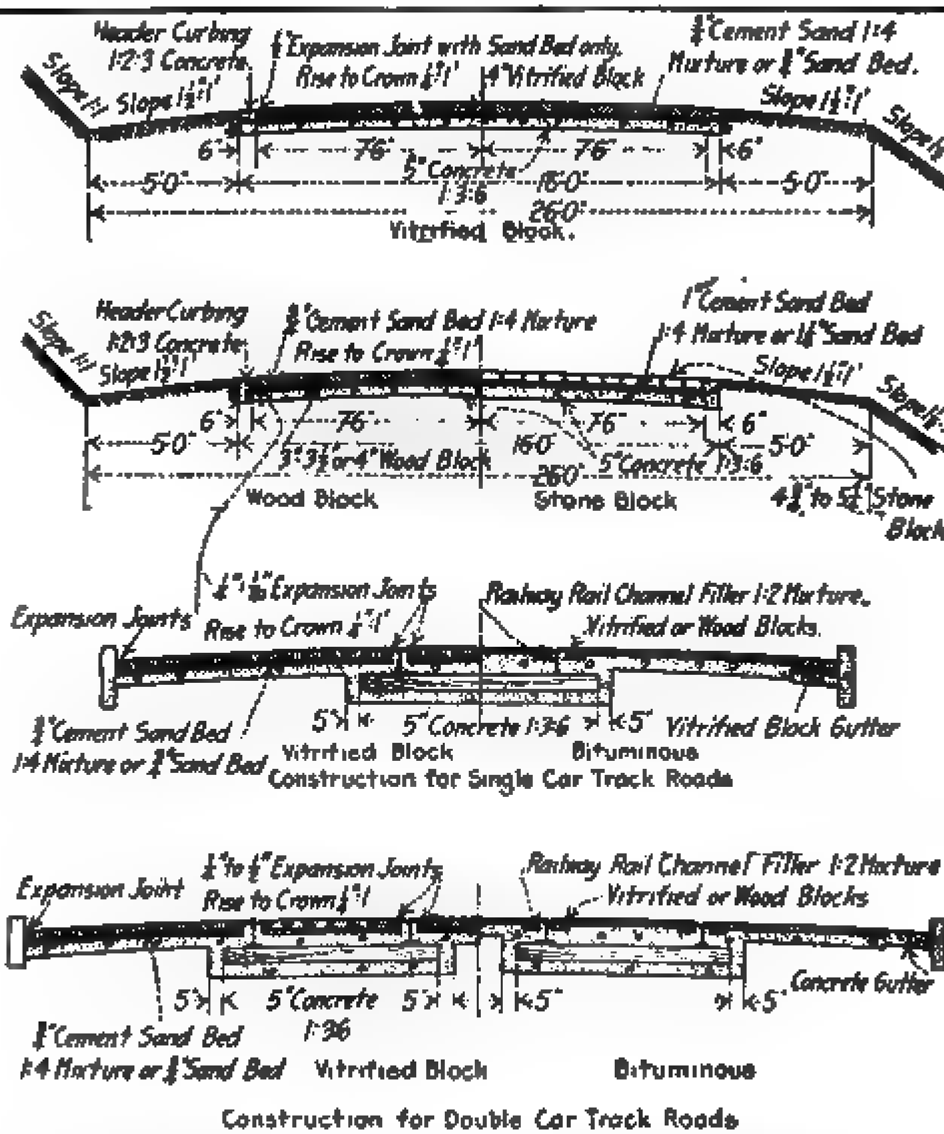


Table Showing Distance below Center for each ¼ Width Point for any Crown Elev.

Curb.	2"	3"	4"	5"	6"	7"	8"
¼ Width	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
½ "	[illegible]	[illegible]	1	[illegible]	[illegible]	[illegible]	2"
¾ "	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]	[illegible]
Center	0"	0"	0"	0"	0"	0"	0"

Table Showing Additional Widths of Surfacing on Curves of Different Rad. and Superelevation per Ft. Width

Radius of Curve, Ft.	Additional Width
[illegible]	5.0
40	[illegible]
60	6.0
80	5.5
[illegible]	4.5
[illegible]	[illegible]
40	4.0
160	3.5
180	3.5
200	3.0
220	3.0
240	2.5
260	2.5
280	2.5
300	2.0

Kind of Surface	Rise per Ft. of Width
Vitrified Block	[illegible]
Wood Block	[illegible]
Bituminous Surface	[illegible]
Concrete Surface	[illegible]
Stone Block	[illegible] to [illegible]
Waterbound Macadam	[illegible] to [illegible]

Note: All Proportions for Concrete as shown on Cross-Sections are Subject to such Variations as are Stated in the Specifications.

Note

In Widening and Superelevation Curves, carry the Regular Grade through on the Center Line of the Roadway, and make all Widening on inside of Curves

Mountain Road Sections.

Discussion.—The desirable requirements for mountain road sections are the same as for the roads previously discussed but on steep sidehill work the width of grading used for ordinary topography would be prohibitive in cost. As most of these roads are natural soil roads the crown is the only element of the section not covered in the previous discussion. For the gravel or stony material usually encountered ¾" to 1' is generally satisfactory. For sand or heavy soils 1" to 1' is better practice. The old idea that crown should be increased on steep grades has been abandoned for while that expedient undoubtedly helped the drainage it caused more inconvenience to traffic than it was worth. In many cases present practice decreases the crown on steep grades to give better vehicle control. Crowns on mountain roads are also affected by the absence of guard rail or other safety provisions. The ordinary symmetrical crown is used where wall or guard rail protects

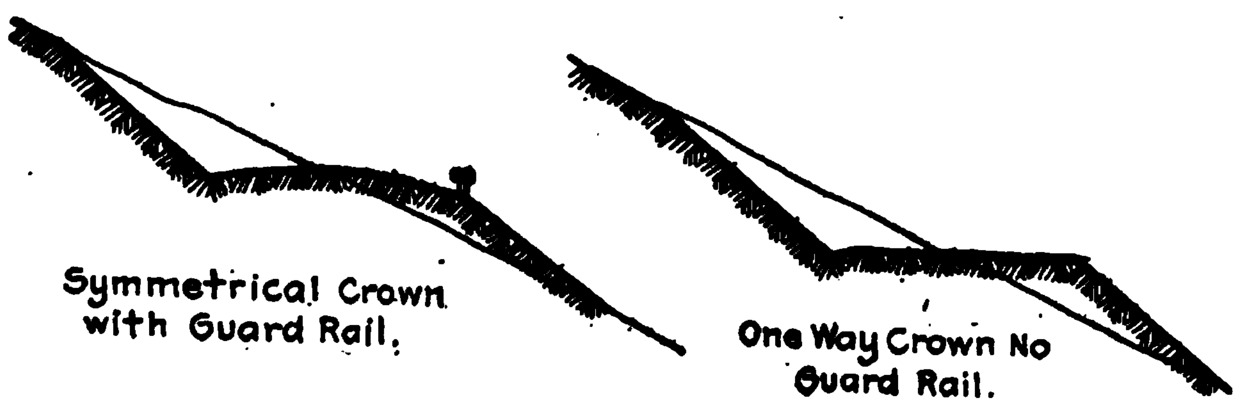


FIG. 16.

the dangerous outside slope but on many roads so much rail would be needed that it is prohibitive in cost and where it can not be used the road is tipped one way in a continuous slant toward the hill so that if a machine skids it will slide in against the cut slope. This kind of a section is not as comfortable to ride as the ordinary crown but if the surface is at all greasy the element of increased safety outweighs any minor inconvenience of side tilt.

The width of section has more effect on cost than any other part of the design. On a new side hill location the relation of width to cost can be roughly established. It will of course vary for different side slopes of the hill and different cut slopes of the excavation but the relation will be approximately as follows, for balanced sections (Table 25, page 285).

Assumed 25° sidehill slope 1 : 1 slope in cut
1½ : 1 slope in fill

(S- 8)	10'	width (ditch to outside of shoulder)	4,300 cu. yd. per mile.
(S-10)	12'	width (ditch to outside of shoulder)	6,100 cu. yd. per mile.
(S-14)	16'	width (ditch to outside of shoulder)	10,200 cu. yd. per mile.
(S-16)	18'	width (ditch to outside of shoulder)	12,800 cu. yd. per mile.
(S-18)	20'	width (ditch to outside of shoulder)	15,400 cu. yd. per mile.

We may say that in general a 20′ width requires about 3½ times as much excavation as a 10′ width. The relative cost of different widths is also affected by the amount of rock excavation which is generally much greater for the wider widths. This depends on the depth of soil overlying the rock. This element affects the cost so much that in certain cases it has been found cheaper to build two separate single track roads for short distances rather than one double track highway.

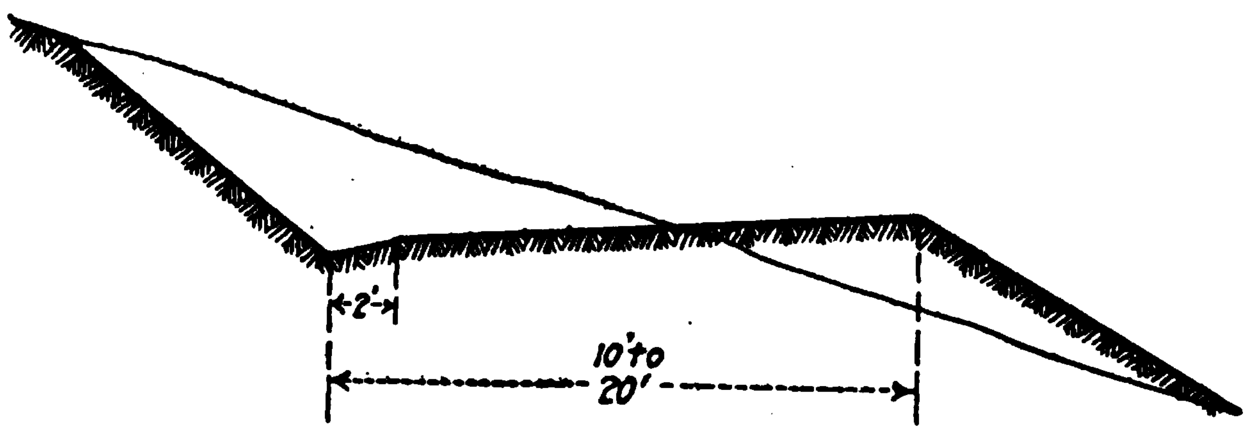
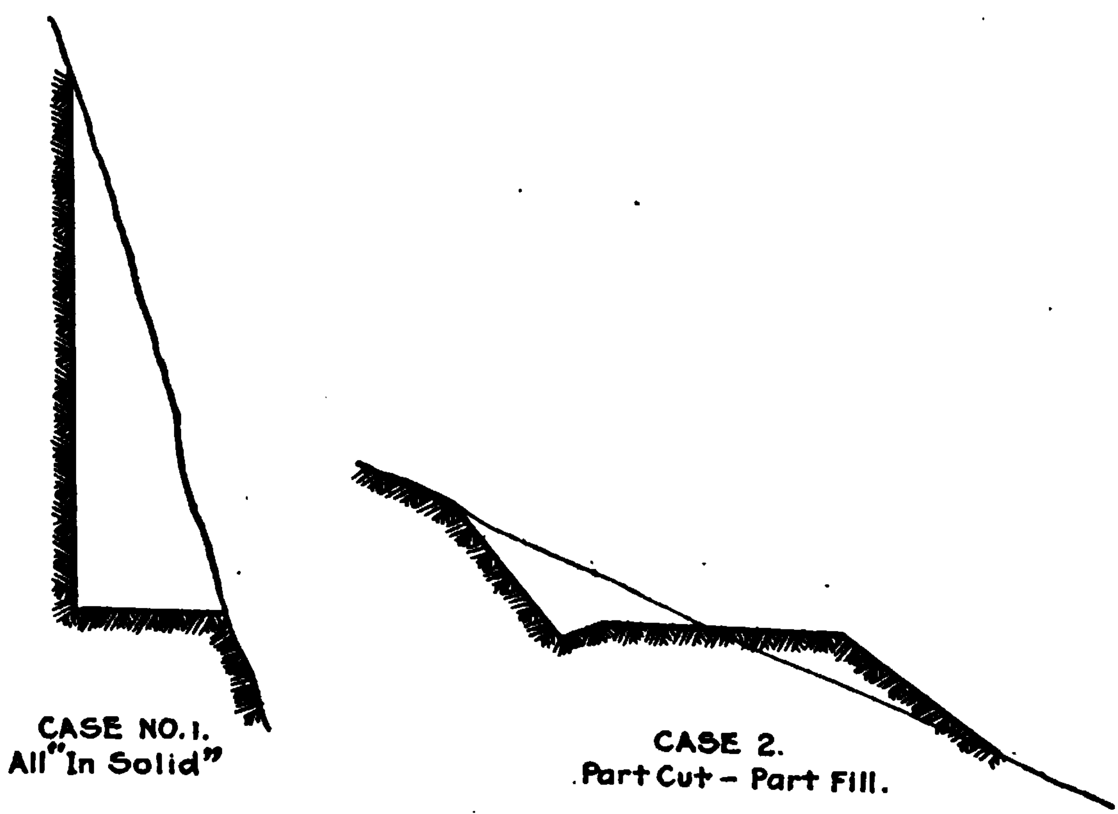


FIG. 17.



Mountain roads are classed roughly as double track or single track, meaning the same as for railroad work, a double line of traffic or a single line with turnouts to allow passing. As each foot of extra width is costly it is important to determine the minimum width of grading that will serve the purpose for these two classifications.

Minimum Width Sidehill Section.—If the roadbed is benched out of solid rock a narrower width will serve as the entire width is

firm and stable. If the section is a balanced section part in cut and part in fill it must be wider as embankments on steep slopes are liable to settle, slide or washout and it is not safe to drive as closely to the edge as in the first case. The amount of the road "in solid" is therefore the prime requisite and "—ft. in solid" is often used as the specification for contract road jobs where engineering design is not used. Present practice favors a minimum single track, total grading width of 10′ in rock or where the outer embankment is sustained by a retaining wall and a total width of 12′ for the ordinary balanced section in earth. Balanced sections are generally used up to 30° side slopes and beyond that toe walls or retaining walls are necessary for earth sections. For a 30° side slope a total grading width of 12′ results in approx. 7′ to 8′ in solid cut. A double track

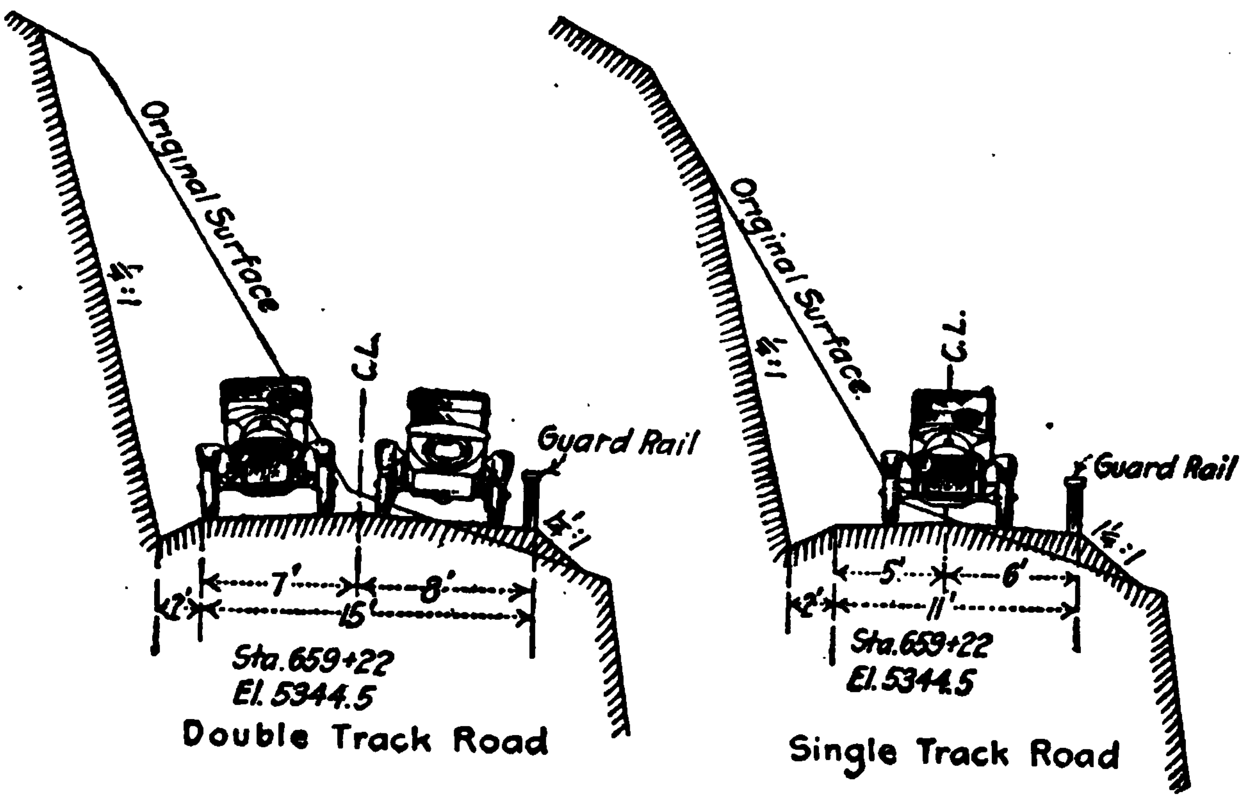


FIG. 18.

section requires a minimum total grading width of 14′ in rock or wall sections and 16′ in balanced earth section which gives approx. 10′ in solid. These same limiting widths apply to turnout sections on single track roads. Where guard rail is used 1 ft. should be added to these widths.

TURNOUTS

On single track roads turnouts are constructed at sufficiently frequent intervals so that drivers can see between them and there will be no danger of meeting at impassable spots. This generally requires from 5 to 10 to the mile. The minimum satisfactory length of turnout is about 60 ft. and the grade should be as easy as possible at these points.

Fill Sections.—Through fill sections must be constructed wider than sidehill sections as the sides are bound to slough off under weather action and all the elements of wear tend to decrease the width; 14′ is considered the minimum width for a single track road and 20′ the minimum for a double track. A symmetrical crown is advisable on fills even on curves. Where guard rail is used increase these widths 2′. These sections occur on only a small per cent. of the length of mountain roads.

Through Cut Sections.—These sections are rare in occurrence; the minimum width, ditch to ditch, for single track roads can be considered as 12′ and for double track 18′. The use of minimum widths for either through cut or fill sections on mountain roads has small effect on cost and for that reason more liberality in their widths is allowable.

Turnpike Sections.—Where the natural ground cross slope is less than 5° turnpiking is the usual construction and the difference in cost of a single or double track is so small that it is not worth considering. For this class of section a minimum of 22′ between ditches will apply to any road and a width of 24′ is generally used.

Selection of Section.—Plate No. 11 illustrates typical mountain road sections.

The turnpike section is used up to side slopes of 5° for continuous balanced work.

The sidehill sections are used above 5° for continuous balanced work. The one way crown is used on all single track sidehill sections where guard rail is lacking. The one way crown is used on unprotected double track roads where the side slope is greater than 15°. The symmetrical crown is used on protected double track roads and on unprotected sections where the side slope is less than 15°.

Through cut and fill sections are used where required by the profile.

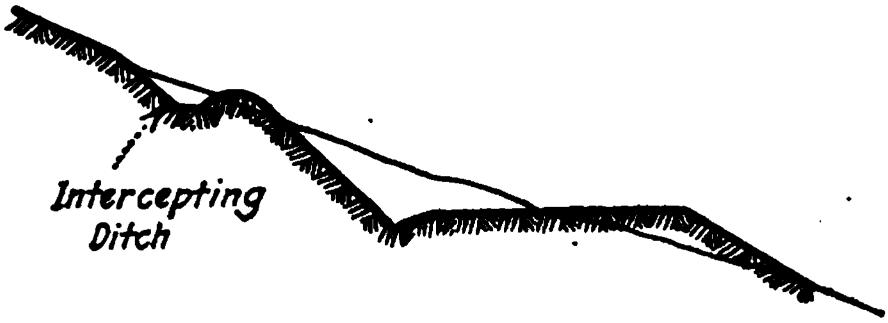
Superelevation is used on curves in cut but rarely on high through hills. The ditch on the upper side of a superelevated through cut section can be omitted if the cut is short.

Cut and fill slopes depend on the natural material and climate and were discussed on page 40. There is too much tendency to use steep slopes to save on construction cost although excessively flat slopes are not necessary or advised it being cheaper to take care of minor slides by maintenance. (For effect of cut slopes see Table 25, page 285.)

Wall Sections.—These sections are used where the natural hill slope is practically as steep or steeper than the stable embankment slope. Toe or retaining walls are necessary for earth embankments where the natural slopes exceeds approx. 30° and for rock fills where the natural slope exceeds approx. 40°. Wall details are described in Chapters VIII and X. Surcharged breast walls are to be avoided if possible.

Intercepting Ditches.—Where considerable water runs down the uphill slope intercepting ditches are used to protect the cut slope and relieve the road ditch of excess water. These ditches discharge

to the nearest cross culvert and are an important part of the design.



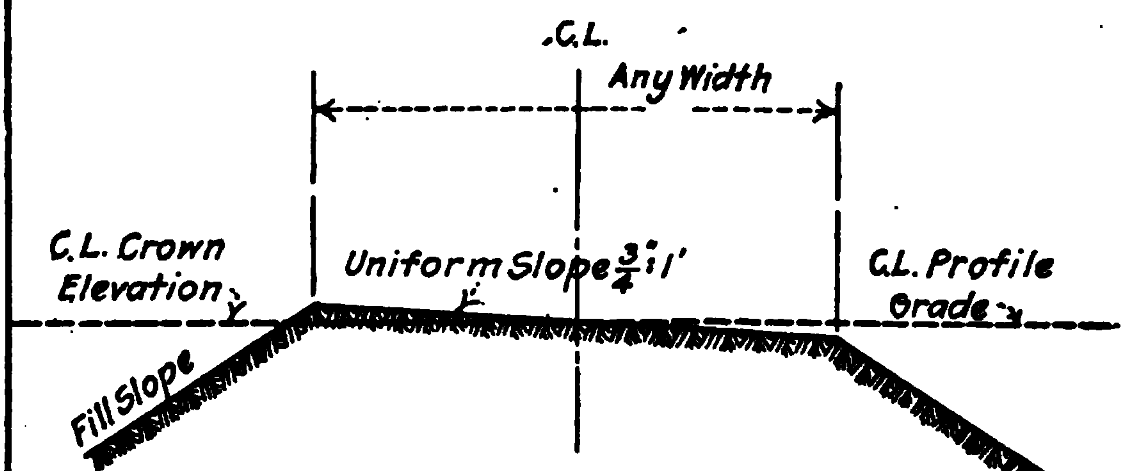
Bench Sections.—Bench sections are used in rock ledge work. (See Sections S–10, Plate 11, and Table No. 25, page 294.)

Summary of Sections.—The entire problem of sections may be summed up as the determination of the minimum widths of grading and hard surface that will serve traffic and drainage requirements. As a general rule current practice handles this part of the design well with the exception of ditches which are often needlessly deep and dangerous and generally fail to regulate ground water which is the only excuse for their use. The use of road ditches for farm drainage is poor policy. Any system of special farm drainage should be separated from the road design except in the matter of culvert elevation.

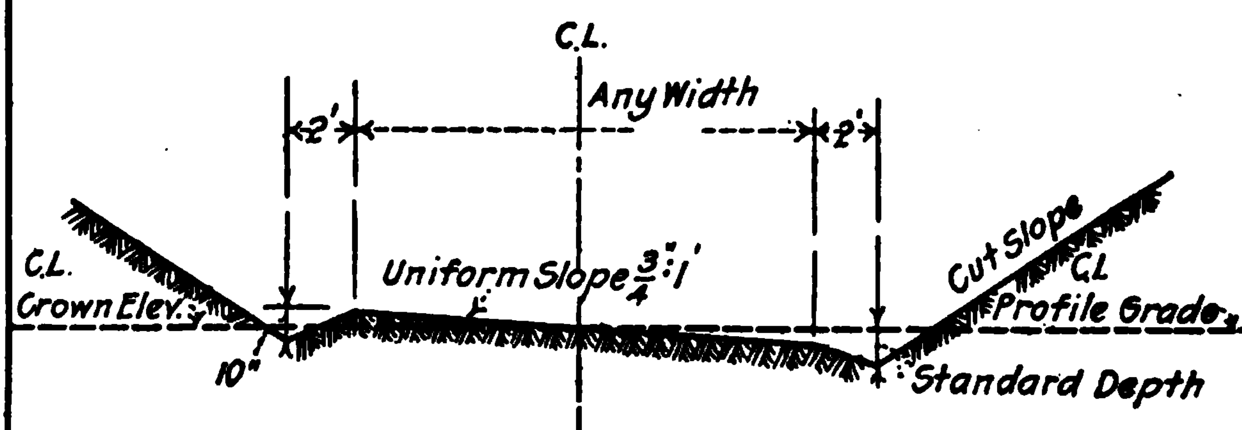
PLATE 11.—MOUNTAIN ROADS.

Typical Super-Elevated Sections on Curves.

Never use a Super Elevated Section where the Inside of the Curve is on a Dangerous Downward Slope.
Use Super-Elevations only on Curves having a Radius Less than 800 ft. Use the same Super-Elevation on 800 ft Radius Curves as on 100' Radius Curves.
The Center Line Elevation and Portion of the Section on the Inside of the Curve remains Normal; the Portion of the Section on the Outside of the Curve is changed as indicated below.



Typical Super-Elevation
In Fill.

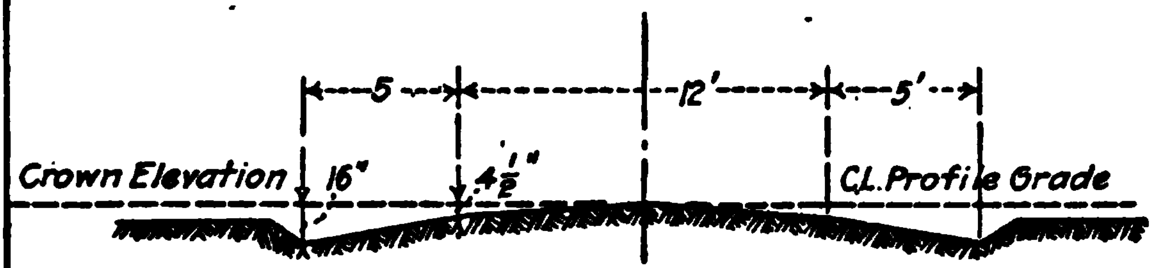


Typical Super-Elevation
In Cut.

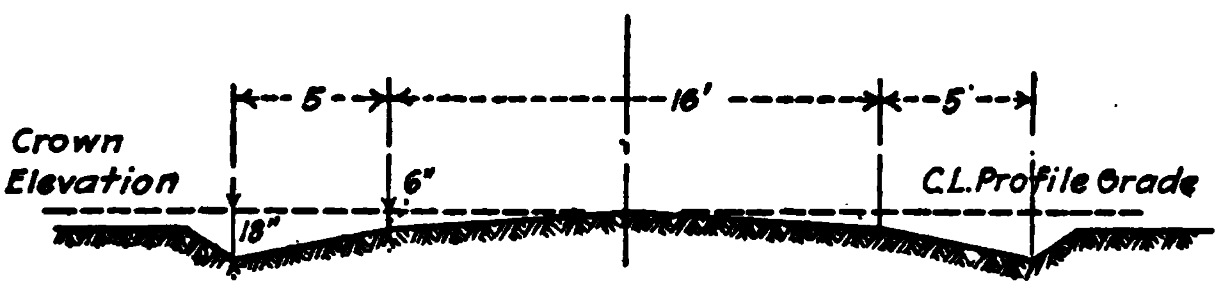
PLATE 11.—(*Continued*)

Typical Turnpike Sections

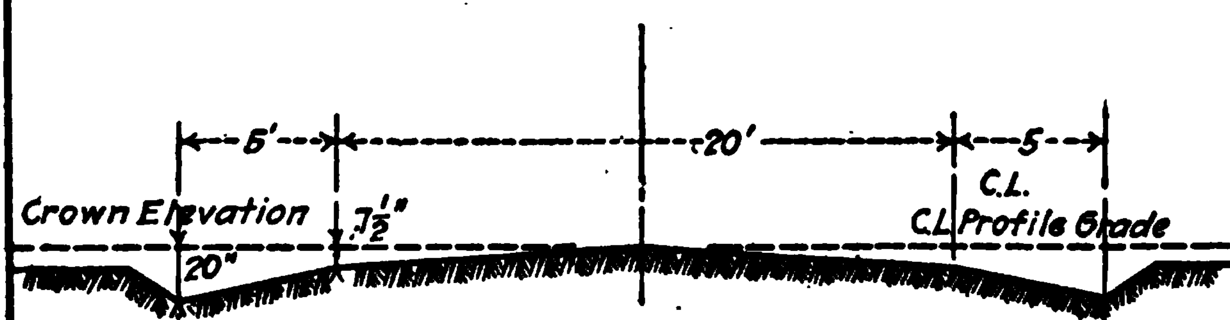
Designated T-Section.



Section T-12
Crown ¾" to 1'



Section T-16
Crown ¾" to 1'



Section T-20
Crown ¾" to 1'

Note:

Where Side Slopes lie between 5 Deg. and 15 Deg use a Combination of S and F Sections, using ½ S Sections in the Cut Side and ½ F Sections on the Fill Side.

Note:

Use Turnpike Sections on Slopes up to 5 Deg.

PLATE 11.—(*Continued*)

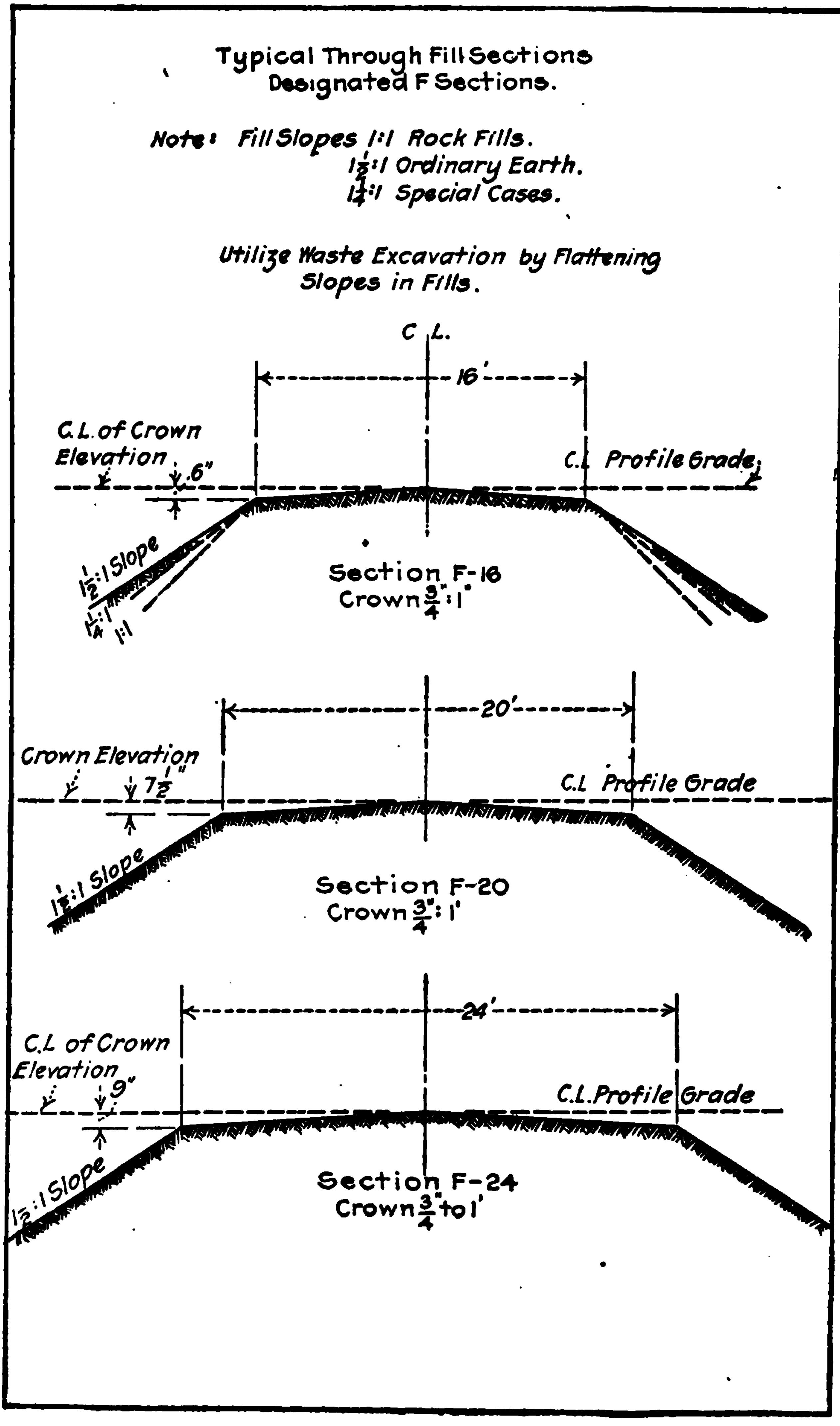


PLATE 11.—(*Continued*)

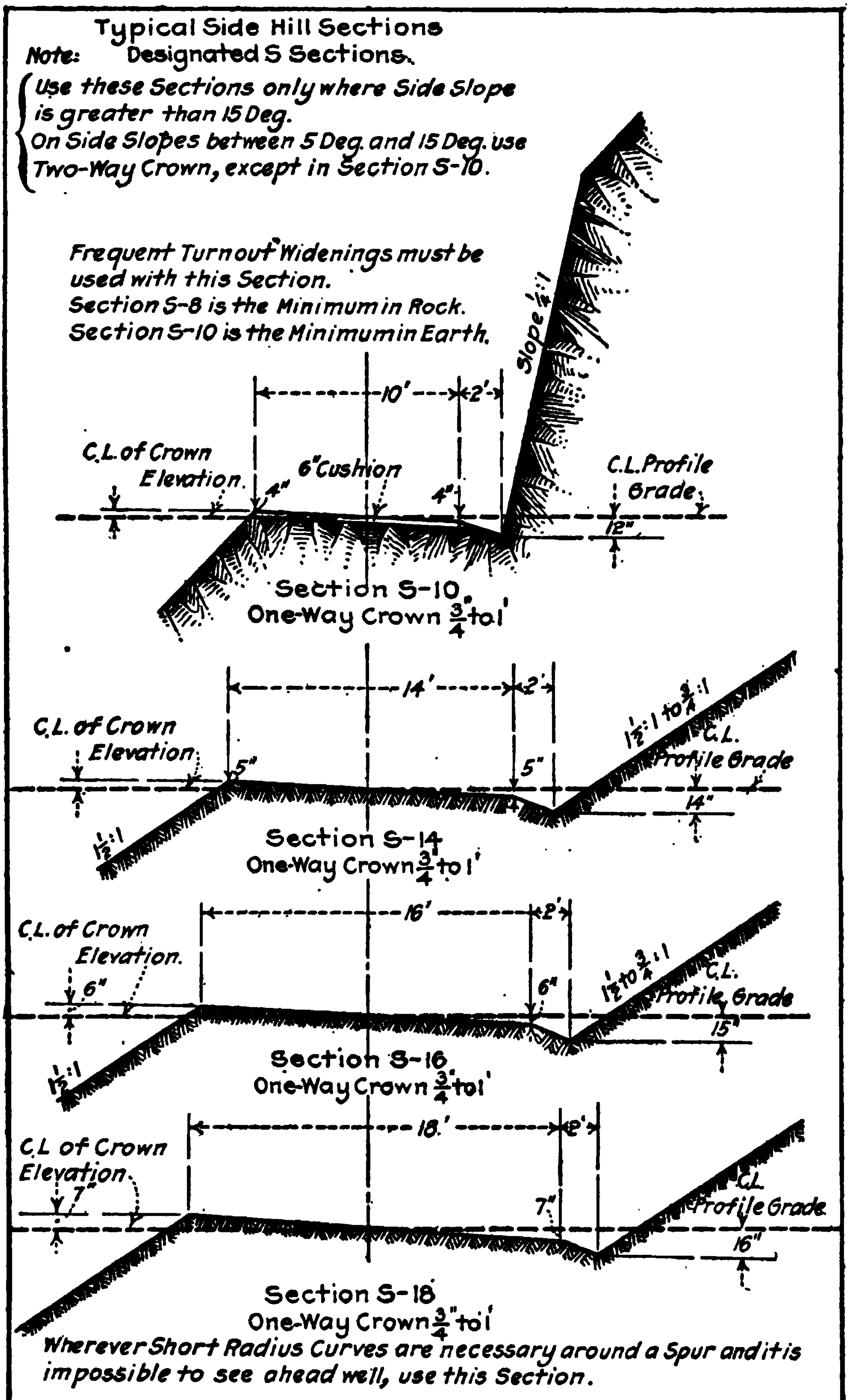


PLATE II.—(*Continued*)

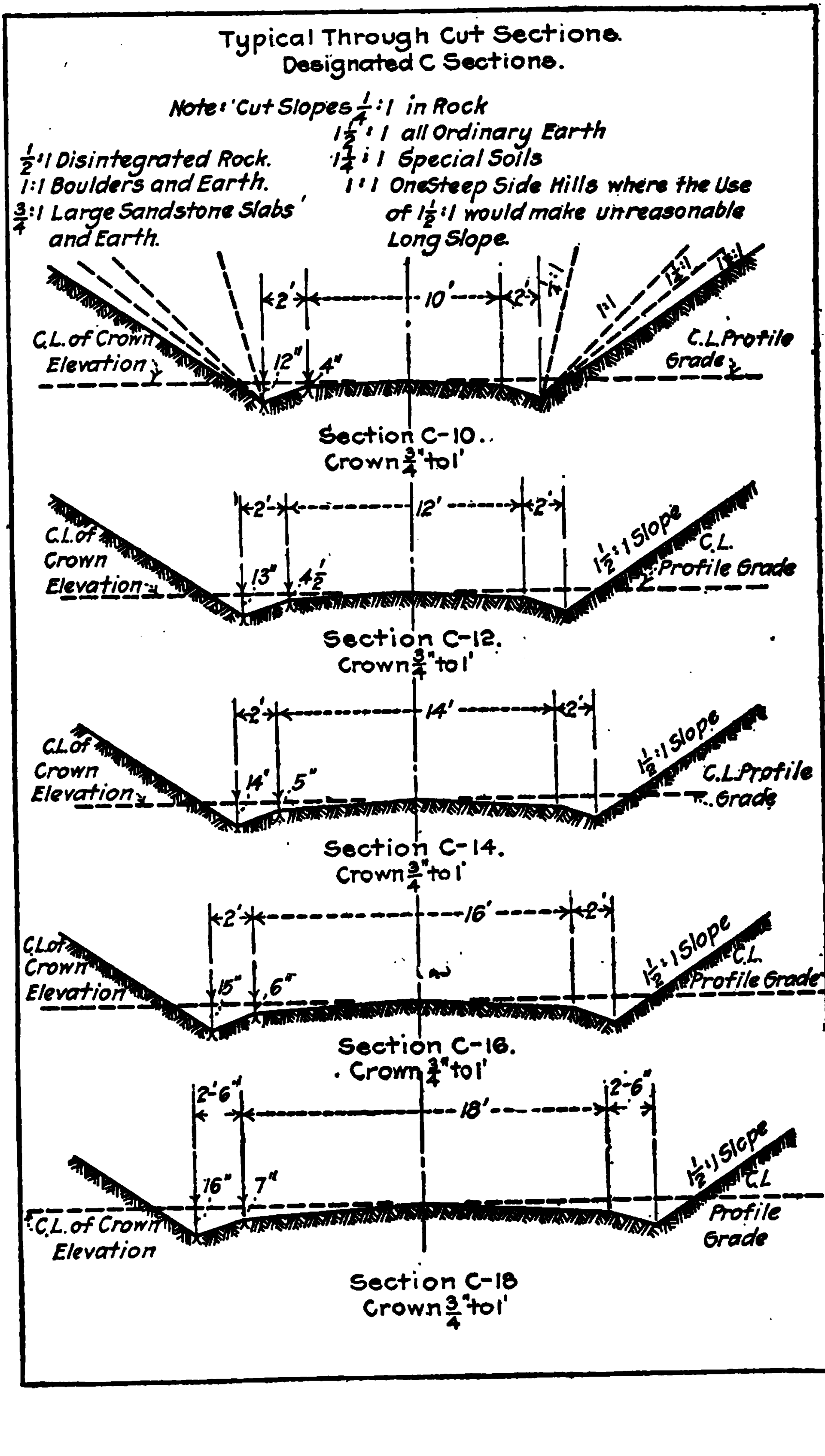
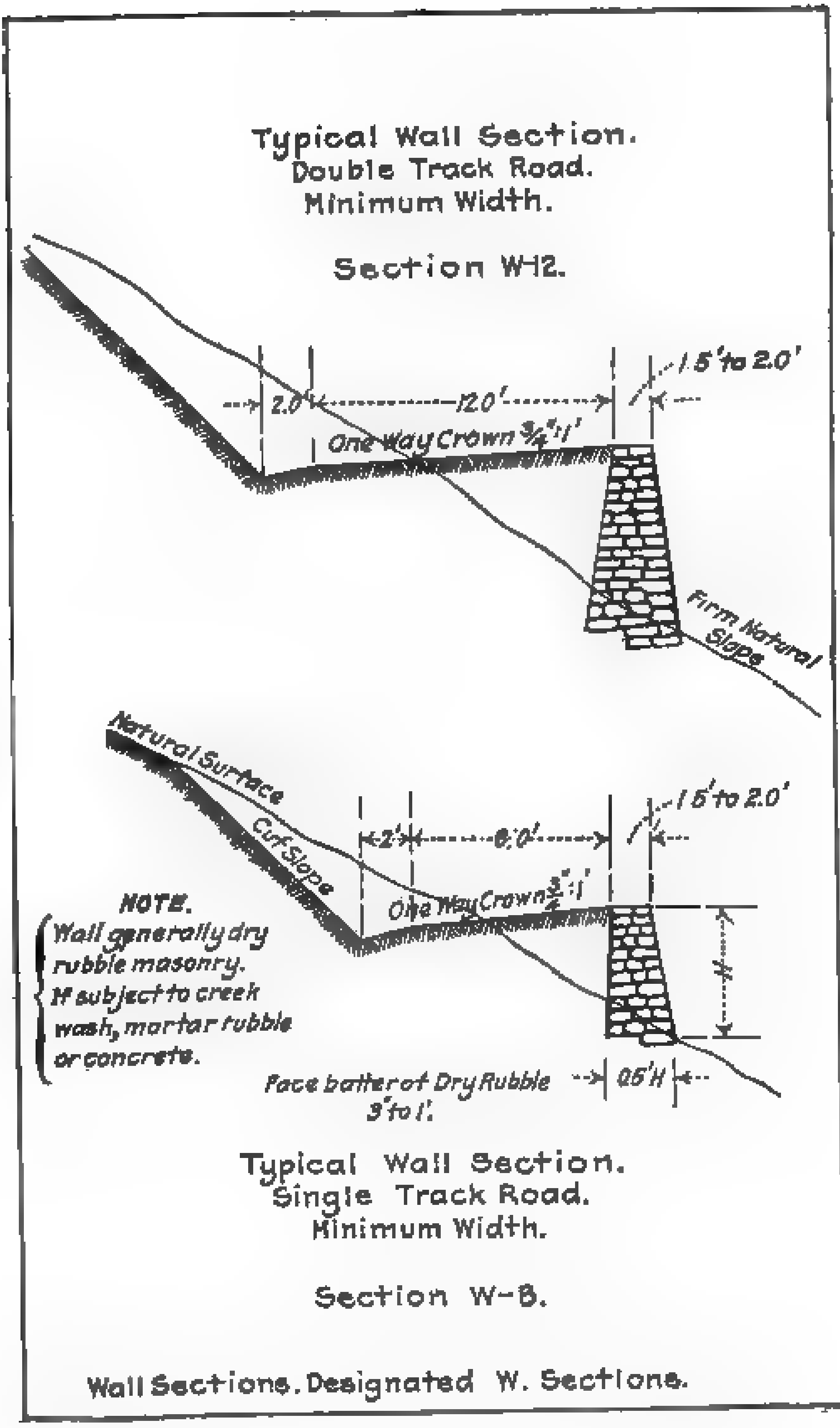


PLATE 11.—(*Continued*)



CHAPTER III

DRAINAGE

(1) General Discussion. (2) Culverts. (3) Small Bridges and Fords. (4) Underdrains.

General Discussion.—There are three classes of drainage problems in road work; cross drainage; longitudinal drainage and sub-surface drainage. Cross drainage includes culverts, bridges and in rare cases fords. Longitudinal drainage includes surface ditches, ditch protections and in unusual cases storm sewers on long hills; and sub-surface structures for collecting ground water cover blind and open throat porous drains.

This chapter deals with the smaller structures only. For the theory and practice of reinforced concrete, masonry or steel long span bridges the reader is referred to the standard works on those subjects. The conditions for transverse drainage to the ditches were given in Chapter II and minimum ditch grades were referred to on page 29. Ditch protection on steep grades, storm sewers, and the flow of water in ditches will be covered in Chapter VIII.

Any complete drainage scheme protects the road from wash and seepage, which requires culverts or bridges at all points where there is a natural cross drainage of accumulated water such as streams, swales, established drainage or irrigation ditches, etc.; at all sags in the road profile and on long grades at frequent intervals to relieve the road ditches of excess water and prevent washouts. The spacing between these ditch relief culverts on sidehill locations depends on the grade, soil, ditch lining and width of section. A narrow 10′ mountain road requires more relief than a 20′ road in the same location as even a small washout will put the narrow road out of commission while a moderately bad ditch scour will not stop traffic in the second case. No set rules on spacing can be given but current practice favors ditch relief culverts on 8% grades at intervals not exceeding 300 feet and on 5% grades not exceeding 500 feet unless cobble gutter or concrete ditch lining is used when the distance can be materially increased. On long cut and fill hills drop inlets into storm sewers are sometimes necessary.

Design.—Culvert and Bridge design considers the size of opening required for the maximum flow, the strength necessary to carry traffic or to hold deep fills; the width of roadway and the type of structure most suitable to the requirements of topography, foundations and available funds. If the funds are limited the cheaper types may be used but all necessary structures must be built not only to protect the road but to establish a reasonable

drainage scheme which as the country develops is recognized and becomes fixed by usage; it is very difficult to change surface drainage in well settled districts without annoying and expensive lawsuits.

Size of Opening.—The size of opening is usually determined by noting the size of the old structure or, if none exists, the size of other structures over the same stream and by inquiries of neighboring residents or the road commissioner as to how the existing structure has handled the water in the past. As a general rule the size of opening or span should not be reduced below that of the present structure but in the case of steel bridges that have been sold to town boards by enterprising bridge companies it is often found that the span is needlessly long. The evidence of existing structures is the most reliable basis of design but the conclusions should be checked theoretically and for small drainage areas in villages and all drainage areas affecting new locations in sparsely settled districts either the physical evidence of high water or some maximum run off formula must be used. Run off formulæ are based on the rate of rainfall, area of the watershed, topography and soil. The rate of rainfall varies for different geographical locations and the length of the storm. Reliable information for any locality can be obtained from the weather bureau. Short storms develop the greatest intensity and produce the largest runoff for small watersheds. The rates reached by these storms should be considered in designing ditch relief culverts or cross culverts with small drainage areas. A liberal basis for these cases is the 5 or 10 minute duration rate of Table 13, page 78. Table 14, page 79, illustrates the method. Most culvert design is based on a 24 hour precipitation as illustrated in Table 16, page 82, and applies to watersheds of say 0.5 sq. mi. and up. Streams requiring structures of over 10′ span generally produce physical evidence of highwater which can be safely used.

Table 15, page 80, gives the size of opening used by the Santa Fe Railroad; Table 17, page 83, gives the size of opening for small culverts used by the New York Central. Table 18, page 83, gives the size of culvert used by the Iowa Highway Commission. These tables serve to illustrate the application of this principle of design.

Weather bureau records show maximum 24 hour precipitations of 7.66 inches at Portland, Oregon, 5.12 inches at Los Angeles, California, 2.06 inches at El Paso, Texas, 7.03 inches at Kansas City, Missouri, 9.40 inches at New York City and 8.57 inches at Savannah, Georgia. These rates are rarely used for runoff computations as they represent extreme cases of rare occurrence. Good practice uses a 24 hour rate of from 4 to 6 inches. Openings based on these rates where the culvert will handle the water without quite running full will take care of unusual cases by the forced discharge due to the formation of a shallow pond on the up stream side of the road. Table No. 19, page 84, gives the normal discharge of small culverts laid at different rates of grade. To illustrate the use of tables 13 to 19 three examples will be given. Suppose water from 2 sq. mi. of flat farming country in the North Atlantic

States is to pass through a culvert having a natural slope of 0.5′ to the hundred.

Table 16 is figured for a 4″ rainfall in 24 hours which is reasonable for this section. This table shows a runoff of 334 second ft. for flat farm land. For a slope of 0.5 ft. per 100 table 19 shows that a 5′ × 5′ culvert will carry the water.

Suppose we have steep rocky ground of say 200 acres or ⅓ sq. mile in Oklahoma and a culvert slope of 2′ per 100. The best data is the Santa Fe table No. 15 which gives an opening of 51 sq. ft. at 10 ft. per second or a run off of 510 second feet. Table 19 shows that a 5′ × 4′ culvert on a 2% grade will carry this but that the velocity is high and the culvert must have a solid bottom and riprap protection at both ends. Where pipes or solid bottom culverts are used high velocity is not objectionable but where the bridge type is used a sufficiently large opening to keep the velocity down to 10 ft. per second or less is advisable.

Suppose a ditch relief culvert drains 2 acres in the cloudburst region and can be laid on a slope of 3 ft. in a hundred. Use last column Table 14 which gives 12 second feet which from Table 19 gives a 16″ pipe.

Strength.—Dead loads are readily determined but reasonable live loads are a matter of judgment. Many of the states limit a vehicle load to 15 tons on improved roads without special permission but loads in excess of this occur now and then. The old culverts and bridges on our roads are practically without exception too light for modern traffic. Permanent culverts should be designed to carry the dead load plus a 20 ton vehicle load with 25% impact. Standard culverts shown in Plate No. 15, page 92, seem needlessly strong but small concrete culverts are generally backfilled and used during construction before they develop their full strength and practical considerations require the excess material. A design load of a 20 ton vehicle with 30% impact is desirable for small permanent solid floor bridges of 10′ to 50′ span and this loading is often used for even timber bridges in States similar to Wyoming where oil development, etc., requires the movement of heavy machinery, although usually where timber is used a 10 ton live load with 50% impact is considered good practice and for mountain roads 6 tons will usually be acceptable. For long span solid floor steel or masonry structures a live load of 150 pounds per square foot plus a 20 ton vehicle with 30% impact is first class modern practice. This value is higher than generally used.

These loadings are safe for military purposes as the following statement of Major General W. M. Black, Chief of Engineers 1917 will show.

"Our existing ordinance liable to accompany a field army will have its heaviest representative in a 12-inch howitzer weighing about 27,000 lb., 18,600 lb. of which are on the front wheels. The base or distance between the front and rear axles is 18 ft.; width of track 7 ft. 4 in. width of tire 8 inches; width of tire shoes 12 inches. This howitzer is drawn by a 75 H. P. caterpillar tractor weighing 25,000 lb. Comparison with the largest present day commercial trucks shows that a road or bridge substantial enough for such will suffice for the ordinance load."

Table No. 51, page 561, gives the safe load for steel I-beams.
Table No. 52, page 563, gives the safe load for timber beams.
Table No. 53, page 564, gives the safe load for concrete slabs.
Table No. 53A, page 565, gives the effect of depth of fill on concrete slabs.
Table No. 54, page 566, gives the safe load for concrete beams.
Table No. 55, page 567, gives the safe load for timber columns.

Width of Bridges.—Culverts are made long enough to accommodate the normal road section. There is nothing more unsightly or dangerous than the narrowing of the normal section at a culvert. First-class design widens the section at culvert locations and even with minimum head room uses an out-to-out dimension of not less than 30 feet. This same rule applies to short span permanent bridges up to about 25′ span which on high type road improvements should have a clear width of 22′ between parapets. Above 25′ spans the roadway width depends largely on the location of the structure and probable traffic but for most main roads a 20′ clear roadway is satisfactory for permanent structures and a 16′ roadway for temporary timber structures. Plates No. 20 to No. 30, page 100 to 124, illustrate current practice.

Type of Structure.—For small drainage areas some form of pipe culvert is generally used which will be discussed in more detail under Culverts.

From 2′ to 5′ spans the box culvert type is popular.

From 5′ to 20′ spans the slab or stringer form of construction is reasonable except under deep fills where the semicircular arch is better practice; from 20′ to 50′ spans Pony Truss or Parapet girder types are available for most conditions or arches where the foundation is suitable. Pony Trusses are desirable up to about 80′ span and beyond that the through Truss type.

The following list illustrates the practice of the Iowa Highway Commission.

1. Box culverts and slab bridges 2′ to 20′ span. Not economical over 20′ span.
2. Reinforced concrete arches 8′ to 100′ span. Foundation must be excellent.
3. Pony truss steel bridges with solid concrete floor 30′ to 80′ spans.
4. Reinforced concrete girders 20′ to 50′ span. Very economical but require careful design and construction. Not economical over 50′ span.

In the matter of type the author desires to emphasize the desirability of simple design particularly for small structures. Mass concrete for sides and bottoms is preferable to thin reinforced sections (see New York Standards, page 92). It may not be as scientific or theoretically as cheap but better results are obtained with the usual inspectors. Road commissioners often do not understand the object of the reinforcement and either leave it out altogether or get it in the wrong place. For large structures where a competent inspector can be employed this objection does not hold but even for such structure mass concrete for abutments, retaining wall, etc., is to be preferred.

TABLE NO. 13.—RATES OF RAINFALL. SHORT STORMS

Short storms of the greatest intensity occur as cloud-bursts in the mountain and arid regions between the Sierras and the foothills of the Rockies. The intensities of these storms are not well recorded but partial records indicate as high a fall as 11 inches in one hour. For these regions culverts for small drainage areas should be made at least twice as large as for eastern or southern conditions. (See last column, table No. 14.)

Maximum intensity of Rainfall for different periods taken from the U. S. Weather Bureau Records. Intensity at rate of inches per hour.

Location	5 Minute Duration	10 Minute Duration	One Hour Duration
Atlanta, Georgia	5.5 in.	5.5 in.	1.5 in.
Boston, Mass	6.7 in.	5.0 in.	1.7 in.
Chicago, Ill	6.6 in.	5.9 in.	1.6 in.
Cleveland, Ohio	5.6 in.	3.7 in.	1.1 in.
Denver, Colo	3.6 in.	3.3 in.	1.2 in.
Detroit, Mich	7.2 in.	6.0 in.	2.2 in.
Duluth, Minn	3.6 in.	2.4 in.	1.4 in.
Galveston, Tex	6.5 in.	5.6 in.	2.6 in.
Jacksonville, Fla	7.4 in.	7.1 in.	2.2 in.
Milwaukee, Wis	7.8 in.	4.2 in.	1.3 in.
Memphis, Tenn	6.6 in.	4.8 in.	1.9 in.
New Orleans, La	8.2 in.	4.9 in.	2.2 in.
Norfolk, Va	5.8 in.	5.5 in.	1.6 in.
Omaha, Neb	6.0 in.	4.8 in.	1.6 in.
Philadelphia, Penn	5.4 in.	4.0 in.	1.5 in.
Savanah, Geo	6.6 in.	6.0 in.	2.2 in.
St. Louis, Mo	4.8 in.	3.8 in.	2.3 in.
Washington, D. C	7.5 in.	5.1 in.	1.8 in.

TABLE 14.—MAXIMUM RUNOFF. SMALL WATERSHEDS
Burkle-Ziegler, Sewer Formula

$$\text{Cubic feet per second per acre reaching culvert} = C \times \left\{\begin{array}{c}\text{Av. cu. ft. rainfall}\\ \text{per second per acre}\\ \text{during heaviest fall.}\end{array}\right\} \times \sqrt[4]{\frac{\text{Av. slope of ground in feet per 1000}}{\text{No. of acres drained}}}$$

C = 0.75 for paved streets and built up business blocks.
C = 0.625 for ordinary city streets.
C = 0.30 for villages with lawns and macadam streets.
Assumed C = 0.25 for farming country. NOTE.—This value is high from the standpoint of sewer design but culverts are short and might better be liberal in size.

One inch of rainfall per hour equals 1 cu. ft. per second per acre.

DISCHARGE IN CUBIC FEET PER SECOND

Area in Acres	Rate of Rainfall 4″ per Hour						**Assumed Runoff Steep Stony Mountain Slopes
	Fall 5′ in 1000		Fall 20′ in 1000		Fall 50′ in 1000		
	C = 0.30	C = 0.25	C = 0.30	C = 0.25	C = 0.30	C = 0.25	Rainfall 8″ per Hour
1	1.8	1.5	2.5	2.1	3.1	2.7	6
2	3.0	2.5	4.2	3.5	5.4	4.5	12
3	4.1	3.4	5.7	4.8	7.2	6.0	18
4	5.0	4.2	7.2	6.0	9.0	7.5	23
5	6.0	5.0	8.5	7.1	10.7	8.9	28
6	6.8	5.7	9.7	8.1	12.2	10.2	33
7	7.7	6.4	10.9	9.1	13.7	11.4	38
8	8.5	7.1	12.0	10.0	15.1	12.6	42
9	9.3	7.8	13.2	11.0	16.5	13.8	46
10	10.1	8.4	14.3	11.9	18.0	15.0	50
20	16.9	14.1	24.0	20.0	30.2	25.2	90
30	23.0	19.2	32.5	27.1	40.7	33.9	120
40	28.5	23.8	40.3	33.6	50.9	42.4	150
50	33.6	28.0	47.7	39.8	60.0	50.0	180
60	38.6	32.2	54.6	45.5	68.7	57.3	200
70	43.3	36.1	61.4	51.2	77.3	64.4	225
80	48.0	40.0	67.9	56.6	85.2	71.0	250
90	52.4	43.7	73.9	61.6	93.1	77.6	275
100	56.7	47.3	80.2	66.8	100.8	84.0	300
200	95.4	79.5	134.6	112.2	169.7	141.4	550
300	129.0	107.7	182.9	152.4	229.7	191.4	750
400	160.0	133.6	227.0	189.2	285.6	238.0	880
500	190.0	158.0	268.0	223.5	336.6	280.5	980
600	216.0	180.0	307.0	256.0	387.0	322.8	1,050
640	230.0	*192.0	323.0	269.0	406.3	338.6	1,100

* 200 second feet by Table 16.
** Based on Santa Fe Table 15.

TABLE 15.—SANTA FÉ RY. SIZE OF OPENING

Area Drained in Square Miles	Areas of Waterways Sq. Ft. Missouri and Kansas A	Okla-homa	Illinois	Area Drained in Square Miles	Areas of Waterways Sq. Ft. Missouri and Kansas A	Okla-homa	Illinois	Area Drained in Square Miles	Areas of Waterways Sq. Ft. Missouri and Kansas A	Okla-homa	Illinois	Area Drained in Square Miles	Areas of Waterways Sq. Ft. Missouri and Kansas A	Okla-homa	Illinois
0.01	2.0	2.0	East of Streator use 60 % of Column A West of Streator use 80 % of Column A	0.85	91.0	91.0	East of Streator use 60 % of Column A West of Streator use 80 % of Column A	4.2	403	409	East of Streator use 60 % of Column A West of Streator use 80 % of Column A	20	970	1062	East of Streator use 60 % of Column A West of Streator use 80 % of Column A
0.02	4.0	4.0		0.90	94.0	94.0		4.4	417	423		22	1015	1120	
0.03	6.0	6.0		0.95	97.0	97.0		4.6	430	436		24	1060	1170	
0.04	7.5	7.5		1.0	100.0	100.0		4.8	443	450		26	1100	1220	
0.05	9.0	9.0		1.1	110.0	111.0		5.0	455	464		28	1140	1275	
0.06	10.5	10.5		1.2	120.0	121.0		5.5	483	493		30	1180	1320	
0.07	12.0	12.0		1.3	130.0	131.0		6.0	509	519		32	1220	1370	
0.08	13.5	13.5		1.4	140.0	141.0		6.5	533	545		34	1255	1415	
0.09	15.0	15.0		1.5	150.0	151.0		7.0	556	572		36	1290	1460	
0.10	16.0	16.0		1.6	160.0	162.0		7.5	579	596		38	1320	1505	
0.15	25.0	25.0		1.7	170.0	172.0		8.0	601	622		40	1350	1575	
0.20	32.0	32.0		1.8	180.0	182.0		8.5	622	644		45	1435	1645	
0.25	38.0	38.0		1.9	190.0	192.0		9.0	641	666		50	1510	1745	
0.30	44.0	44.0		2.0	200.0	202.0		9.5	660	689		55	1580	1840	
0.35	51.0	51.0		2.2	220.0	223.0		10.0	671	709		60	1650	1930	
0.40	56.0	56.0		2.4	240.0	244.0		11.0	710	745		65	1720	2020	
0.45	62.0	62.0		2.6	260.0	264.0		12.0	740	781		70	1780	2100	
0.50	66.0	66.0		2.8	280.0	284.0		13.0	775	815		75	1840	2180	
0.55	70.0	70.0		3.0	300.0	304.0		14.0	805	857		80	1900	2255	
0.60	74.0	74.0		3.2	321.0	326.0		15.0	835	893		85	1980	2330	
0.65	78.0	78.0		3.4	340.0	345.0		16.0	865	930		90	2015	2405	
0.70	81.0	81.0		3.6	357.0	362.0		17.0	890	951		95	2065	2475	
0.75	85.0	85.0		3.8	373.0	379.0		18.0	920	998		100	2120	2545	
0.80	88.0	88.0		4.0	388.0	394.0		19.0	945	1020		110	2220	2690	

120	2315	2820	East of Streator use 60 % of Column A West of Streator use 80 % of Column A	300	3615	4690	East of Streator use 60 % of Column A West of Streator use 80 % of Column A	850	5940	7640	East of Streator use 60 % of Column A West of Streator use 80 % of Column A	2000	8820	11450	East of Streator use 60 % of Column A West of Streator use 80 % of Column A
130	2405	2955		325	3770	4860		900	6080	7875		2200	9240	11960	
140	2500	3080		350	3900	5040		950	6230	8170		2400	9605	12490	
150	2580	3240		375	4035	5220		1000	6380	8410		2600	9970	12995	
160	2665	3330		400	4165	5400		1100	6705	8720		2800	10370	13680	
170	2745	3445		450	4385	5660		1200	6960	9030		3000	10640	14370	
180	2820	3560		500	4610	5920		1300	7230	9340		3500	11445	15050	
190	2900	3665		550	4825	6175		1400	7480	9650		4000	12160	15740	
200	2970	3775		600	5030	6440		1500	7725	9960		4500	12825	16475	
220	3115	3980		650	5230	6695		1600	7960	10270		5000	13500	17275	
240	3245	4152		700	5420	6335		1700	8195	10580		5500	14080	18125	
260	3370	4330		750	5610	7170		1800	8390	10890		6000	14520	18975	
280	3495	4510		800	5800	7400		1900	8625	11200		6500	15140	19825	

Note.—The above classification by states is for convenience only, and merely denotes the general characteristics of topography and rainfall. Column A in table is prepared from observations of streams in southwest Missouri, eastern Kansas, western Arkansas and the southeastern portion of the Indian Territory. In all of this region, steep rocky slopes prevail and the soil absorbs but a small percentage of the rainfalls, and indicates larger waterways than are required in western Kansas and the level portions of Missouri, Colorado and New Mexico or Western Texas. This table is based on data procured from different western railroads and from actual surveys and on a 6" rainfall in 24 hours taken from Government statistics, with the understanding that most of it falls in 6 or 8 hours, and velocity under bridge or through opening is 10' per second. From the above it is obvious that each waterway should be given a certain amount of individual consideration, and if it is desirable to depart from waterways in table full explanation of conditions and reason for departure should be given.

Approved.

R. A. Rutledge,
Chief Engineer.

**See Vol. XI, No. 2, April, 1906, Journal Western Soc of Engrs. for report on Dun's waterway table.
C. E. O., April 13, 1914.**

TABLE 16.—MAXIMUM RUNOFF, DICKENS FORMULA

$D = C\sqrt[4]{M^3}$ Runoff expressed in second feet.

The following tabulation is for a 24 hour precipitation of 4″ rain and for topography similar to the farming sections of the Eastern Atlantic States. For 6″ in 24 hours correct the quantities in proportion to C as follows.

4″ Rainfall		6″ Rainfall	
Flat Country	Flat C = 200	Country	C = 300
Rolling Country	C = 250	Rolling Country	C = 325
Hilly Country	C = 300	Hilly Country	C = 350

For steep stony watersheds and a 6″ rainfall use the Oklahoma Column of Table 15.

Area in Square Miles	Flat Country C 200	Rolling Country C 250	Hilly Country C 300
0.1 = 64 acres	36	45	54
0.2	60	75	90
0.3	81	101	121
0.4	100	125	150
0.5	119	149	180
0.6	136	170	204
0.7	153	191	229
0.8	169	211	253
0.9	185	231	277
1.0	200	250	300
2.0	334	417	501
3.0	456	570	684
4.0	564	705	846
5.0	668	835	1002
6.0	764	955	1146
7.0	860	1075	1290
8.0	950	1188	1426
9.0	1038	1297	1556
10.0	1122	1402	1682
20.0	1890	2362	2834
30.0	2560	3200	3840
40.0	3180	3975	4770
50.0	3760	4700	5640
60.0	4310	5400	6480
70.0	4840	6050	7260
80.0	5360	6700	8040
90.0	5840	7300	8760
100.0	6320	7900	9480

or areas under 0.1 square mile, see Table 14.

TABLE 17.—NEW YORK CENTRAL AND HUDSON RIVER R. R. CULVERTS FOR SMALL DRAINAGE AREAS.

Steep, Rocky Ground. Acres	Flat Cultivation, Long Valley. Acres	Size. Diameter in Inches	Equivalent Capacity. Pipes
5	10	10"	
10	20	12"	
20	40	16"	
25	50	18"	two 16" pipes
30	60	20"	two 16" pipes
45	90	24"	two 18" pipes
70	140	30"	two 24" pipes
110	220	36"	two 30" pipes
150	300	42"	two 30" pipes
180	360	48"	two 36" pipes
280	560	60"	

NOTE. — To be used only in the absence of more reliable information, particularly existing culverts over the same stream.

TABLE 18. CULVERT DESIGN. IOWA STATE HIGHWAY COMMISSION[1]

Size of Culvert Opening	Maximum Acres	Minimum Acres
2′ × 2′	70	28
4′ × 4′	376	140
6′ × 6′	1300	520
8′ × 8′	2700	1120
10′ × 10′	5000	2000

CULVERTS

Engineers do not differ much in the design of these structures. For high type roads they should be permanent; should be large enough to take the flood flow; should if possible be self-cleaning; must admit of being cleaned easily and as previously stated must be long enough to accommodate the normal width of road section. For low type roads the requirements are the same except that temporary or semi-permanent culverts may be used if the funds are limited. The different kinds are as follows:

Concrete or masonry culverts..........	Permanent
Cast iron pipe culverts................	"
Double strength vitrified clay pipe.....	Semi-permanent
Ordinary concrete pipe culverts........	" "
Corrugated metal pipe culverts........	" "
Dry rubber masonry culverts..........	" "
Timber and log culverts..............	Temporary

TABLE 19. APPROXIMATE DISCHARGE CAPACITY CAST-IRON PIPE AND SMALL CONCRETE BOX CULVERTS

Slope in Feet per 100	12″ C. I. P. Vel.	12″ C. I. P. Dis.	14″ C. I. P. Vel.	14″ C. I. P. Dis.	16″ C. I. P. Vel.	16″ C. I. P. Dis.	18″ C. I. P. Vel.	18″ C. I. P. Dis.	20″ C. I. P. Vel.	20″ C. I. P. Dis.	22″ C. I. P. Vel.	22″ C. I. P. Dis.	24″ C. I. P. Vel.	24″ C. I. P. Dis.
	Velocity in Feet per Second / Discharge in Cu. Ft. per Second													
0.5					4.5	6	5.0	9	5.4	12	5.8	15	6.2	19
1.0					6.8	9	7.0	12	7.7	17	8.2	22	9.2	29
2.0	7.4	6	8.3	9	9.2	13	10.0	18	10.9	24	11.5	30	12.3	39
3.0	9.2	7	10.3	11	11.2	16	12.2	21	13.4	29	14.2	37	14.8	46
4.0	10.6	8	11.8	12	13.1	18	14.2	25	15.3	34	16.5	43	17.2	54
5.0	11.8	9	13.3	14	14.6	20	16.2	28	17.3	38	18.0	48	19.0	60
6.0	13.0	10	14.6	15	16.2	23	17.5	31	19.0	41	20.0	53	21.3	67
Area Sq. Ft.	0.78		1.07		1.39		1.76		2.17		2.64		3.14	
Value of R	0.25		0.29		0.33		0.37		c.42		0.46		0.50	

CONCRETE BOXES

Slope in Feet per 100	2′×1.5′ Vel.	2′×1.5′ Dis.	2′×2′ Vel.	2′×2′ Dis.	3′×2′ Vel.	3′×2′ Dis.	3′×3′ Vel.	3′×3′ Dis.	4′×2′ Vel.	4′×2′ Dis.	4′×3′ Vel.	4′×3′ Dis.	4′×4′ Vel.	4′×4′ Dis.	5′×3′ Vel.	5′×3′ Dis.	5′×4′ Vel.	5′×4′ Dis.	5′×5′ Vel.	5′×5′ Dis.
0.5	7.0	21	7.7	31	8.6	52	9.7	87	9.7	78	10.8	130	11.6	186	11.9	179	13.0	260	13.8	340
1.0	10.0	30	10.4	42	12.5	75	13.7	123	13.7	110	15.0	180	16.7	267	16.9	254	18.5	370	19.0	475
2.0	14.0	42	14.8	59	17.5	105	19.0	171	19.0	152	22.0	264	23.6	378	23.8	357	26.2	523	28.0	700
3.0	17.2	52	18.3	73	21.6	130	23.5	212	23.5	188	26.5	318	29.0	464	29.5	443				
4.0	20.0	60	21.0	84	24.8	149	27.5	248	27.0	216	30.5	366								
5.0	22.6	68	23.5	94	27.5	165	31.0	279	31.0	248										
6.0	24.0	72	26.0	104	30.0	180														
Area Sq. Ft.	3.0		4.0		6.0		9.0		8.0		12.0		16.0		15.0		20.0		25.0	
Value of R	0.60		0.66		0.86		1.0		1.0		1.2		1.33		1.36		1.54		1.66	

Note: — Table 19 is figured from Church's diagrams of Kutters formula using n = 0.011; the use of these diagrams for short culverts is approximate only but it is sufficiently close for the purposes for which this table is intended.

Cast iron pipe or concrete box culverts are generally used on high class improvements. Corrugated metal, concrete or vitrified pipe and dry masonry on low class improvements and timber or log culverts in mountain road work.

For moderate sized drainage areas the culvert opening is proportioned to the runoff but for small areas the size is determined by the convenience of cleaning rather than by the discharge capacity. Where sufficient fall can be obtained to make the culvert self-cleaning, a 12″ pipe is feasible under shallow fills but where the flow is sluggish, nothing less than a 16″ or 18″ pipe will serve satisfactorily. Long culverts under deep fills should never be smaller than 2′ wide and 3′ high to permit cleaning by hand if necessary.

The self-cleansing velocity of flow for sand and earth particles is about one foot per second; for coarse gravel about three feet per second (Ogden's Sewer Design, page 134). A pipe laid on a slope that gives a velocity of five feet per second when flowing one quarter full should keep clean. This requires a fall of approx. two feet per hundred for a 12″ pipe and is the minimum grade at which the 12″ size should be used.

It is our opinion that a culvert should have the same slope as the stream bed. If given a greater slope the outlet end tends to clog and if a lesser the inlet end will plug. It is unusual for culverts to fill badly except when placed at the foot of a steep hillside where the stream velocity is naturally reduced. At such points an extra large structure should be designed with the idea of providing sufficient waterway even after the contraction caused by this settlement has occurred. Such a culvert should be cleaned after each freshet. The use of paved dips in the roadway at such points in place of culverts is not advised as they are dangerous and cause accidents unless very gradual. A man not familiar with the road often loses control of his car. Ditch relief culverts on grades should be laid at an angle of about 45° with the center line in order not to retard the water at the inlet end.

More trouble is experienced from culverts becoming filled with ice due to alternate freezing and thawing weather. This is particularly true of small culverts draining springs. Culverts as large as 2 × 2 have frozen solid in this manner and if this condition is anticipated the size should be regulated accordingly or trouble will be experienced during the spring break up. The following ingenious expedient has been successfully used on roads where the culverts fill with ice and snow during the winter. A small pipe is suspended inside of the normal culvert. In the fall this small pipe is plugged and in the spring just as the snow begins to melt the plugs are removed and the first water flowing through the small pipe melts the ice and snow rapidly for the entire length of the culvert so that it is generally completely free to handle the main spring runoff.

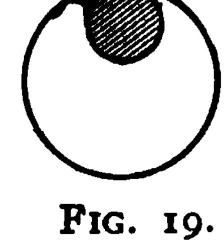


FIG. 19.

Where pipe culverts are laid on steep slopes special buttresses well imbedded in the hard slope should be provided to prevent

crawl or slip. Well built headwalls should hold up to say 12° slope and beyond that extra anchors should be provided.

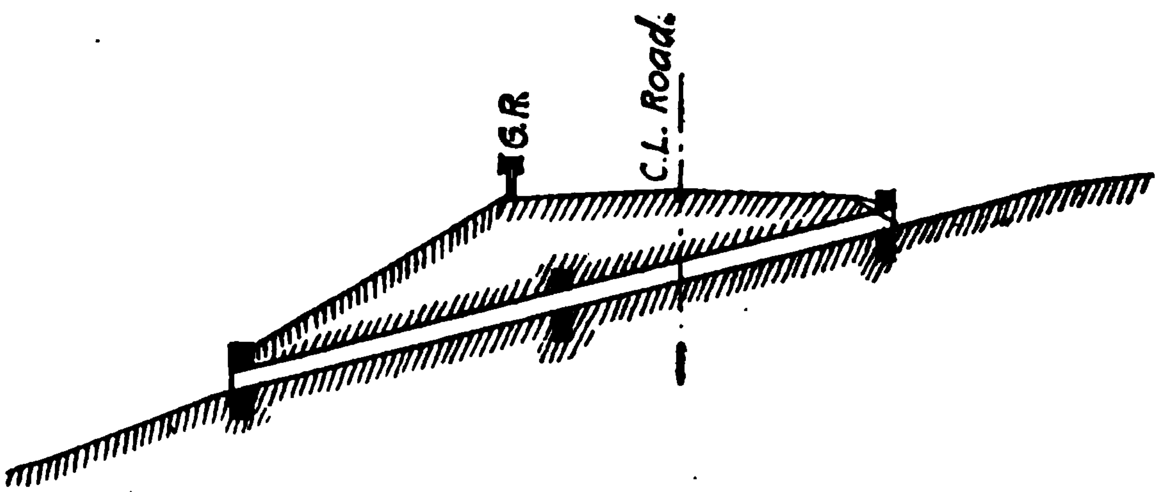


FIG. 20.

In designing culverts under side roads, the length must be great enough to provide an easy turn for traffic; many times a saving

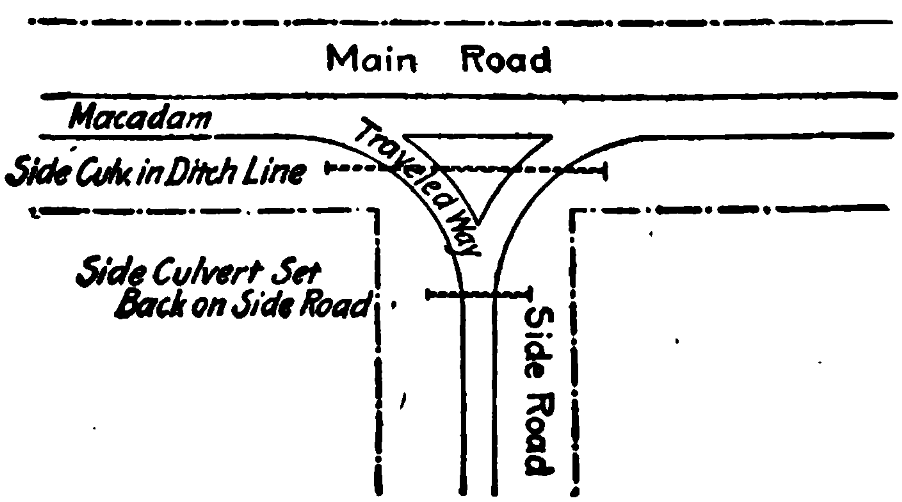


FIG. 21.

in length can be made by placing the culvert a short distance down the side road as shown in Figure 21.

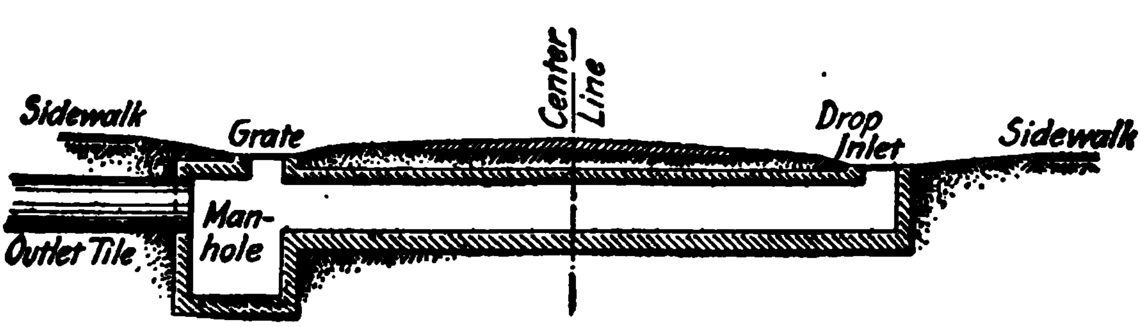


FIG. 22.

Figure No. 22 shows a form of culvert often used in village streets where deep ditches at the culvert site would be objectionable.

While vitrified pipe or concrete pipe are not recommended for cross culverts in high-class improvements they are the most suitable

construction for ditch drainage under driveways etc., the wooden boxes built by some departments are not economical which is shown in the following estimate of relative cost of small unimportant culverts given by A. R. Hirsch in Wisconsin Road Pamphlet No. 4.

Kind	Size of Opening	Length	First Cost and Maintenance for 100 Years
3" Hemlock box	15 in. sq.	24′	$252.00
Concrete box	15 in. sq.	20′	40.00
Concrete pipe	18 in.	20′	35.00
Single strength V. T. P. .	18 in.	30′	41.00
Double strength V. T. P. .	18 in.	28′	42.00
Cast-iron pipe	18 in.	24′	166.00
Corrugated steel	18 in.	26′	196.00

Relative Cost of Culverts.—The relative cost depends largely on the location, material available and length of haul. The following costs are approximately correct for the northeastern states during the years 1912–1914.

Table 21 gives comparative costs for permanent culverts and shows that cast iron is generally not economical over 18″ in diameter. Pipe is to be preferred where the headroom is small.

The following list shows the approximate cost per ft. of vitrified and corrugated metal pipe culverts.

	12″	15″	18″	24″	36″	48″
Vitrified pipe culverts	$0.60	$0.90	$1.10	$2.00	$3.75	
Corrugated metal culverts............	1.25	1.50	1.80	2.75	4.00	$6.50

Corrugated metal is to be preferred to vitrified tile if the headroom is small as it is not as likely to fail under heavy loads.

Small log culverts cost approx. as follows:

Size of Opening	Approx. Cost per Foot
12″ × 18″	$1.30
12″ × 24″	1.40
14″ × 36″	1.60
24″ × 36″	1.70

The difference in cost between corrugated metal and log culverts is not enough to warrant the use of small lot structures except in unusual cases.

TABLE 21. APPROXIMATE COSTS OF SMALL CONCRETE CULVERTS SIMILAR TO PLATE 15 AND CAST-IRON PIPE CULVERTS

Length Feet	Concrete Culverts, Size of Opening[1]: 2'×1.5'	2'×2'	3'×2'	3'×3'	4'×2'	4'×3'	4'×4'	5'×3'	5'×4'	5'×5'	Cast-Iron Pipe Culverts: 12" Pipe	14" Pipe	16" Pipe	18" Pipe	20" Pipe	24" Pipe	Length Feet
20	$63	$76	$79	$97	$90	$107	$127	$127	$147	$170							20
22	68	81	86	104	97	115	136	137	158	181							22
24	72	86	92	111	104	124	145	146	169	193	$44	$52	$ 61	$ 72	$ 83	$107	24
26	77	91	99	118	111	132	154	156	179	204							26
28	81	96	105	126	118	140	163	166	190	216							28
30	86	101	111	133	126	148	172	175	200	227	52	63	74	88	101	131	30
32	91	106	118	146	133	156	181	185	211	238							32
34	95	111	124	148	140	164	190	194	221	250							34
36	100	118	131	155	147	172	199	204	232	261	61	74	87	104	119	156	36
38	104	121	137	162	154	180	208	214	242	273							38
40	109	126	143	169	162	188	217	223	253	284							40
42	114	131	150	177	169	196	226	233	263	295	69	84	100	120	137	180	42
44	118	136	156	184	176	205	235	243	274	307							44
46	123	141	163	191	183	213	244	253	284	318							46
48	127	146	169	199	190	221	253	262	295	330	78	95	114	135	156	205	48
50	132	151	175	206	198	229	262	272	305	341							50
Cost per ft.	$2.30	$2.50	$3.20	$3.63	[illegible].60	$4.06	$4.50	$4.83	$5.27	$5.70	$1.45	$1.80	$2.18	$2.62	$3.06	$4.07	

Note: — These approximate costs figured on a basis of $8.00 per cu. yd. for Concrete Decks and Parapets; $6.00 per cu. yd. for Concrete Bottoms, sides, and wings, 10 cts. per sq. ft. for Expanded Metal in place. Medium weight Cast-Iron Pipe figured at $35.00 per ton in place. $9.00 per cu. yd. for Headwalls. See page 688–697 for quantities of 2d and 3d cl. concrete.

[1] Span is noted 1st, that is a 3' × 2' Culvert means Span 3' Height 2'.

Plates 12, 13 and 14 show standard pipe culverts.

Plate 15 shows first-class simple massive box culvert design. This is as satisfactory a type as there is in use.

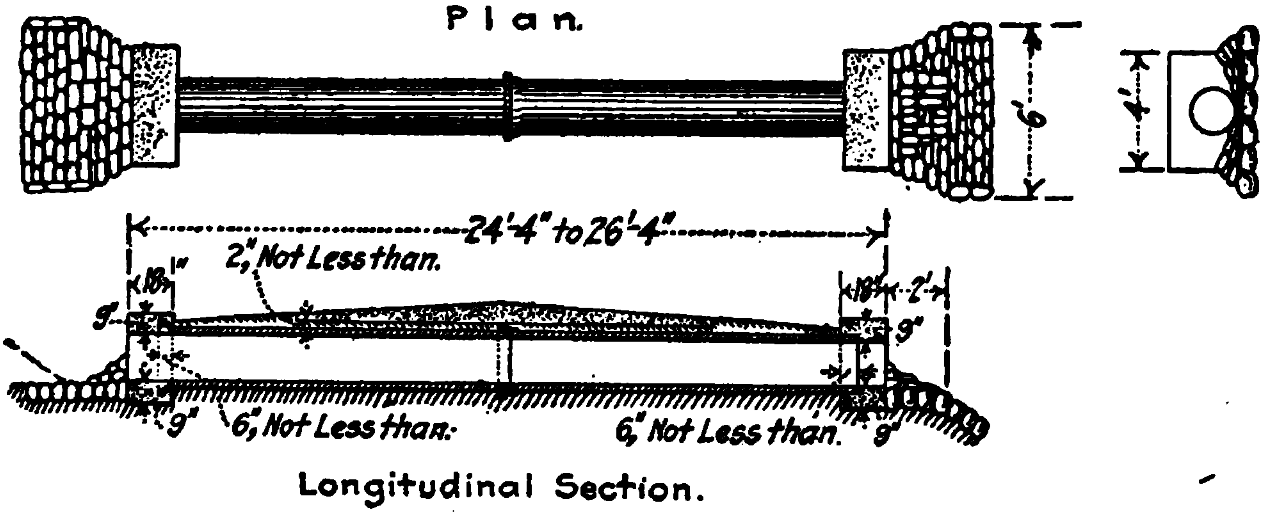
Plates 16 and 17 show good examples of semicircular and circular culvert practice.

Plate 18 shows the combined masonry and concrete type which is suitable where stone is plentiful and concrete costly.

Plate 19 shows log culverts used on mountain roads.

The shape of opening for small concrete culverts should permit the use of collapsible forms.

PLATE 12.—CAST IRON PIPE CULVERT. NEW YORK STATE STANDARD.



SMALL SPAN BRIDGES

The area of opening, width, live loading and economical type were discussed in the first of the chapter. Most ordinary soils afford satisfactory foundations for small span bridges but piles must be used for muck or quicksand and are advisable if much scour is anticipated which can not be prevented by rip rap protection. Pile foundations are required for all large structures where rock foundations are not available and are desirable for any concrete structure over 30′ span.

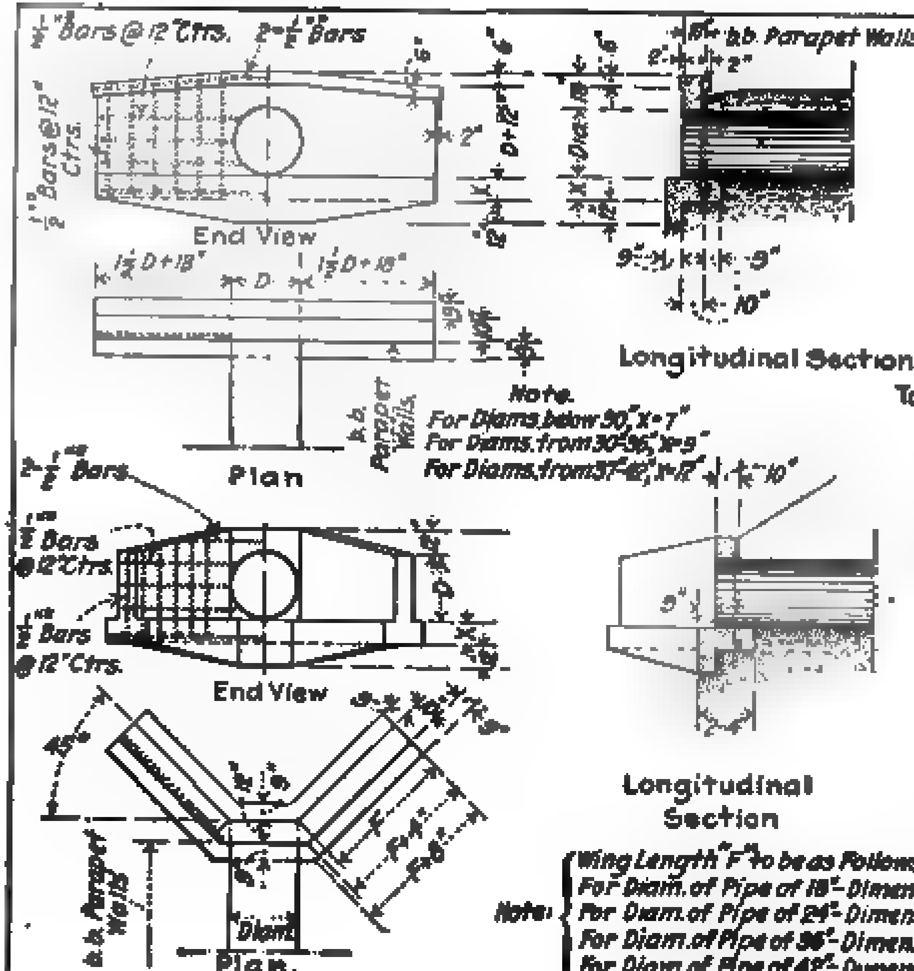
The safe foundation load on various soils recommended by the "New York Building Code" and "Baker's Foundations" are as follows:

New York Building Code

Soft clay	1 ton per square foot
Ordinary sand and clay in layers, wet and springy	2 tons " " "
Loam, clay or fine sand, firm and dry	3 " " " "
Dry firm coarse sand, stiff gravel or hard clay	4 " " " "

(*Continued on page* 98.)

PLATE 13.—METAL PIPE CULVERTS. STATE OF IOWA.



Note: Wing Length "F" to be as Follows:—
For Diam. of Pipe of 18"—Dimension F to be 4'-0"
For Diam. of Pipe of 24"—Dimension F to be 4'-6"
For Diam. of Pipe of 36"—Dimension F to be 5'-0"
For Diam. of Pipe of 42"—Dimension F to be 5'-6"

Table of Specifications for Sheet Metal Culverts.

Diameter	Min. Sheet Thickness	Min. Rivet	Max. Rivet Spacing	Remarks
12 in.	¼ in.	½ in.	6 in.	Farm Crossings only
15 "	¼ "	½ "	6 "	
18 "	¼ "	½ "	6 "	
24 "	¼ "	½ "	6 "	
30 "	¼ "	⅝ "	6 "	
36 "	3/16 "	⅝ "	6 "	
42 "	3/16 "	⅝ "	6 "	

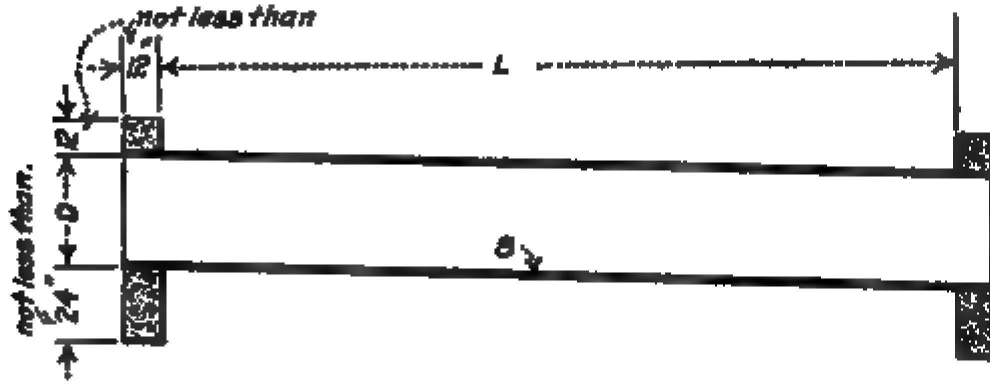
Table of Specifications for Corrugated Culverts.

Diameter	Min. Gage	Min. Rivet	Max. Rivet Spacing	Remarks
12 in.	16 lb.	⅜ in.		This Size for Farm Driveways
15 "	14 "	⅜ "		
18 "	[illegible]	⅜ "		Not to be used where Fill over Culvert exceeds 6 ft.
24 "	[illegible]	⅜ "		
30 "	12 "	⅜ "		Not to be used where Fill over Culvert exceeds 4 ft.
36 "	12 "	⅜ "		
42 "	12 "	⅜ "	2 in. ea. Cor.	

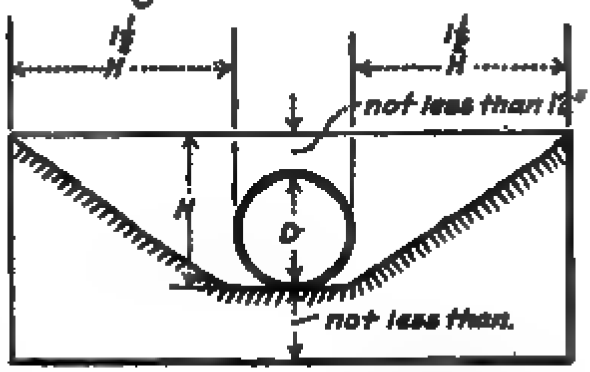
16 lb., 14 lb. Etc.

Note: Corrugated Pipe for use on Township Roads and Farm Driveways only, or for Temporary Repairs on County Roads.

Plate 14.—Corrugated Metal Culverts. State of New Hampshire.



Longitudinal Section



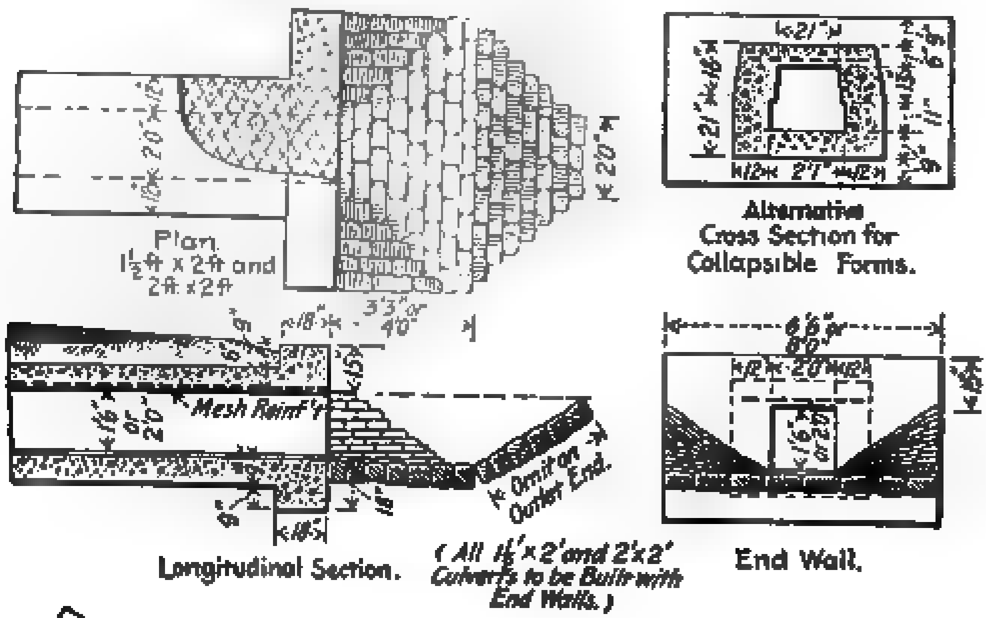
End Elevation.

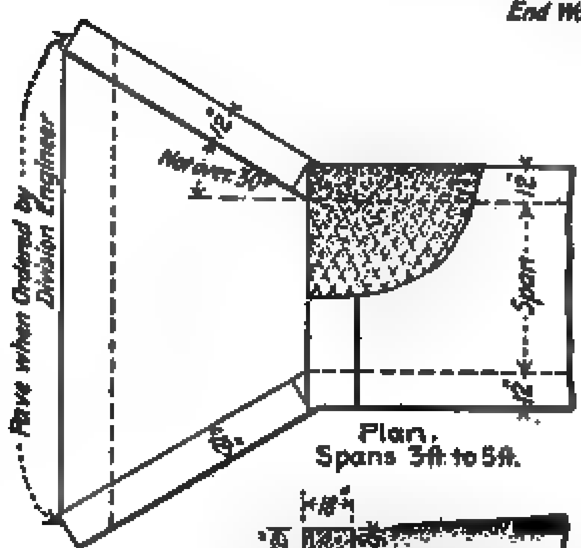
TABLE OF PROPERTIES.

Diameter "D"	Slope "S"	Capacity, Cu Ft. per Sec.	Concrete Cu Yds.
10"	0.048	1.64	1.75
12"	0.033	2.36	2.0
14"	0.025	3.21	2.3
16"	0.020	4.20	2.6
18"	0.016	5.31	2.9
20"	0.012	6.54	3.2
24"	0.010	9.42	3.8
30"	0.007	14.73	4.9
36"	0.005	21.21	6.1
Velocity = 3.0 Ft per Sec "n" = 0.027			

Quantities Figured from Minimum Dimensions.

PLATE 15.—NEW YORK STATE SMALL BOX CULVERTS.





Span	Thickness of Slab	Thickness of Abutment	Mesh Reinforcement lbs. per sq. ft.
2'0"	6"	12"	0.6
3'0"	6"	12"	1.2
4'0"	6"	12"	1.2
5'0"	8"	12"	1.2

Table of Dimensions.

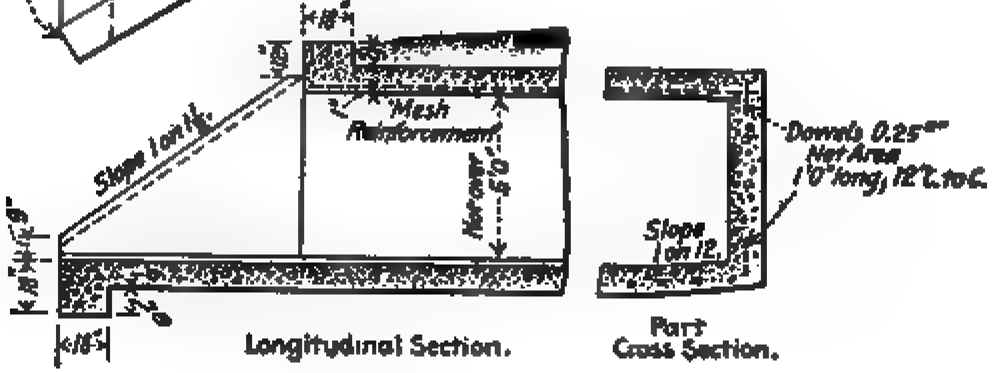


PLATE 16.—MASSACHUSETTS STANDARD FOR CONCRETE ARCH CULVERTS.

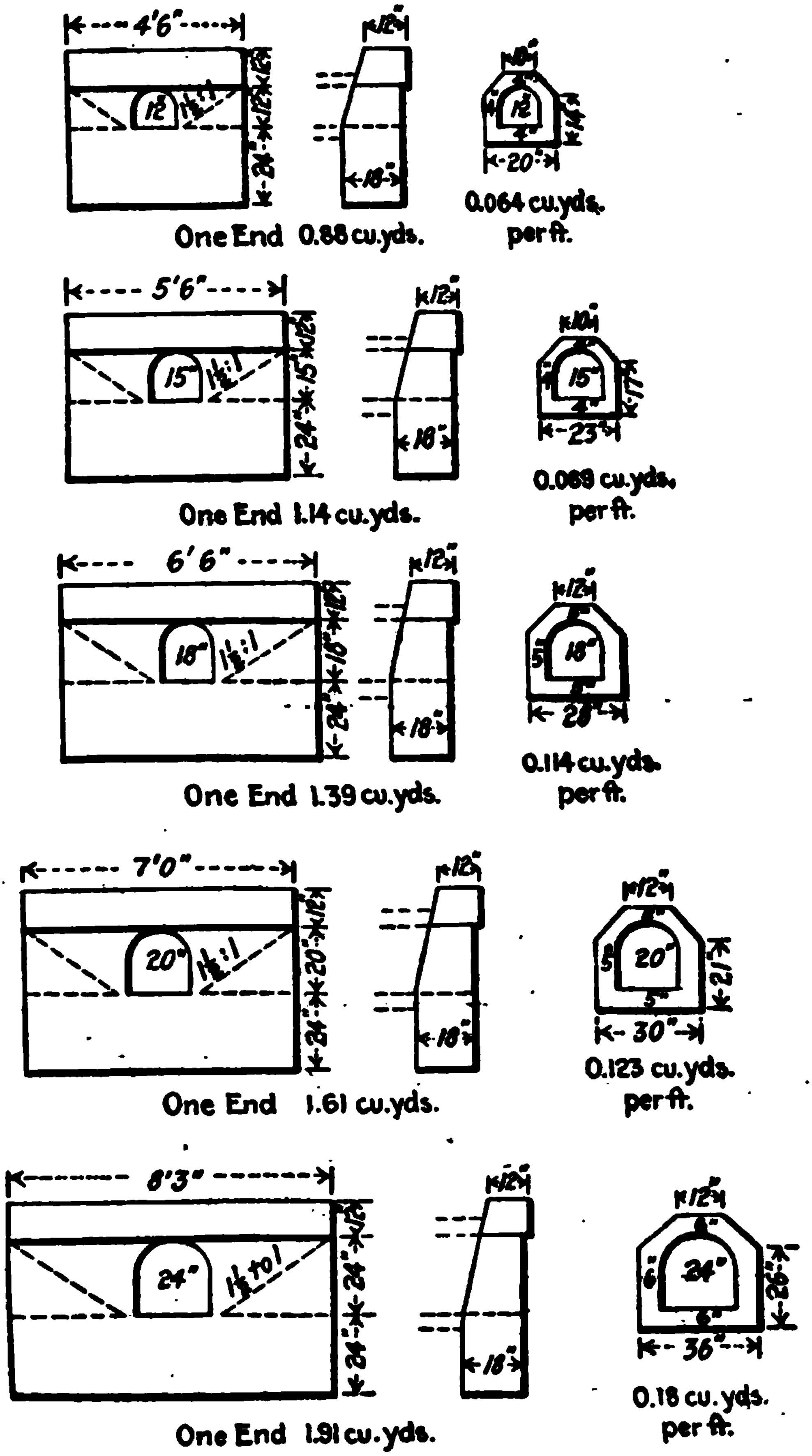


PLATE 17.—STATE OF IOWA 18″ CIRCULAR CONCRETE CULVERTS

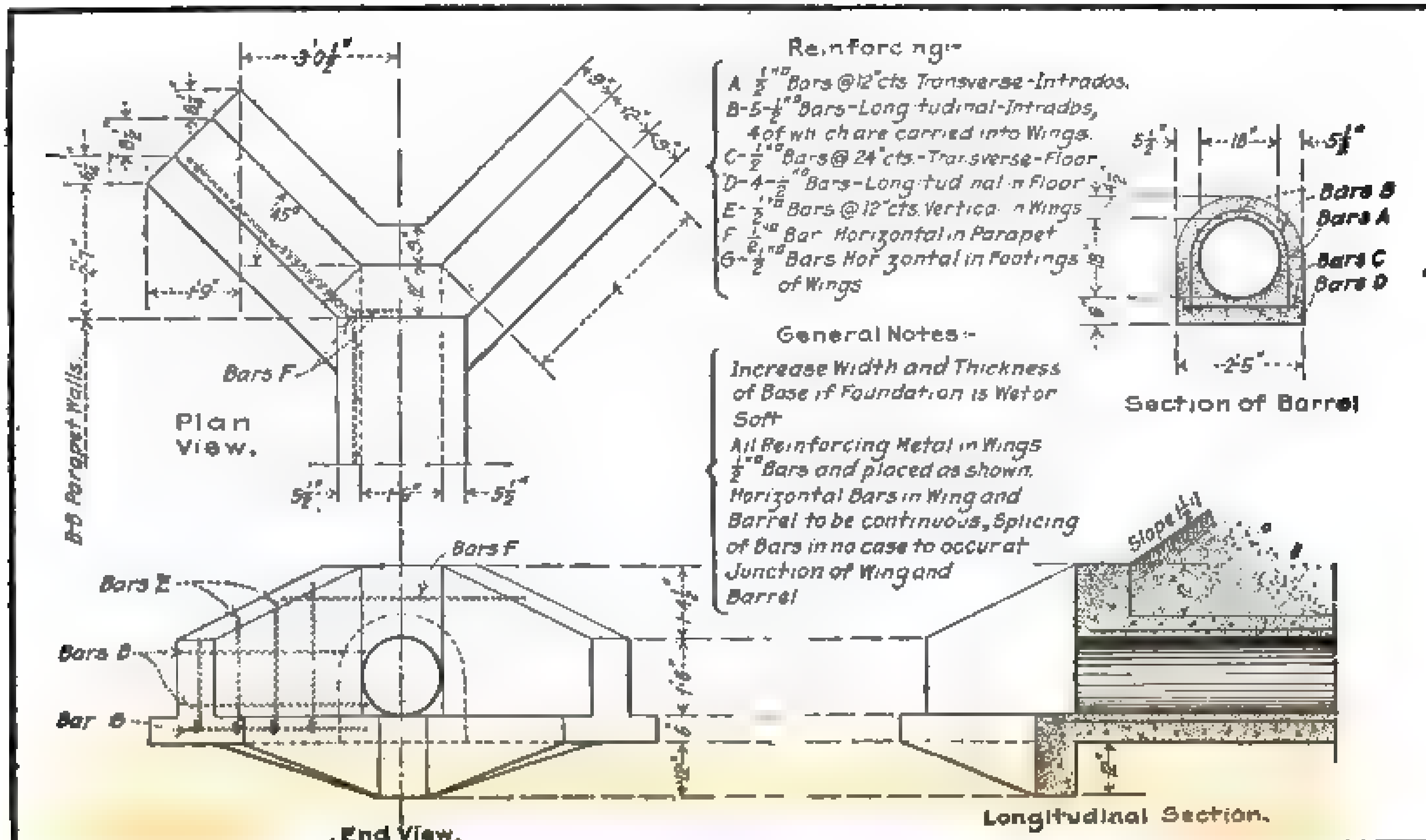


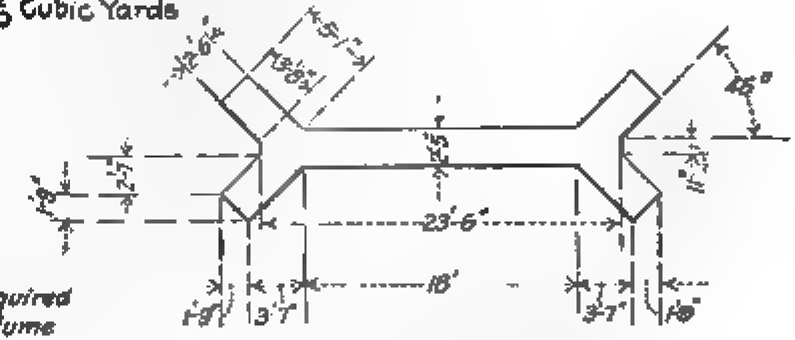
PLATE 17.—(*Continued*)

18 inch Circular Culvert
Bill of Reinforcing Steel and Quantities of Concrete Materials.
Cubic Contents of Culvert 20 ft Back to Back of Parapet Walls
Equals, $5\frac{4}{10}$ Cubic Yards

Concrete Materials.

Item	Quantity Req. for Culvert 20 ft b-b Parapet Walls	Additional Amount per Ft Additional Length of Barrel
	If Sand and Stone are Used.	
Sand	2.38 Cu. Yds.	0.055 Cu. Yds
Stone	4.80 " "	0.112 " "
Cement	7.9 bbls. or 31.6 Sack	0.182 bbls. or 0.73 Sacks
	If Gravel alone is Used	
Gravel	6.2 Cu. Yds	0.125 Cu. Yds
Cement	10.25 bbls. or 41.0 Sacks	0.238 bbls. or 0.95 Sacks

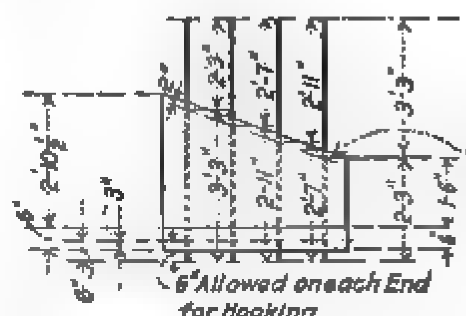
Note { *The Table above gives Theoretical Quantities required To allow for Shrinkage add 20 Per Cent to the Volume of Sand and Stone or Gravel given in Table.*



Staking Diagram.

Bill of Reinforcing for Culvert.
20 ft. b-b Parapet Walls

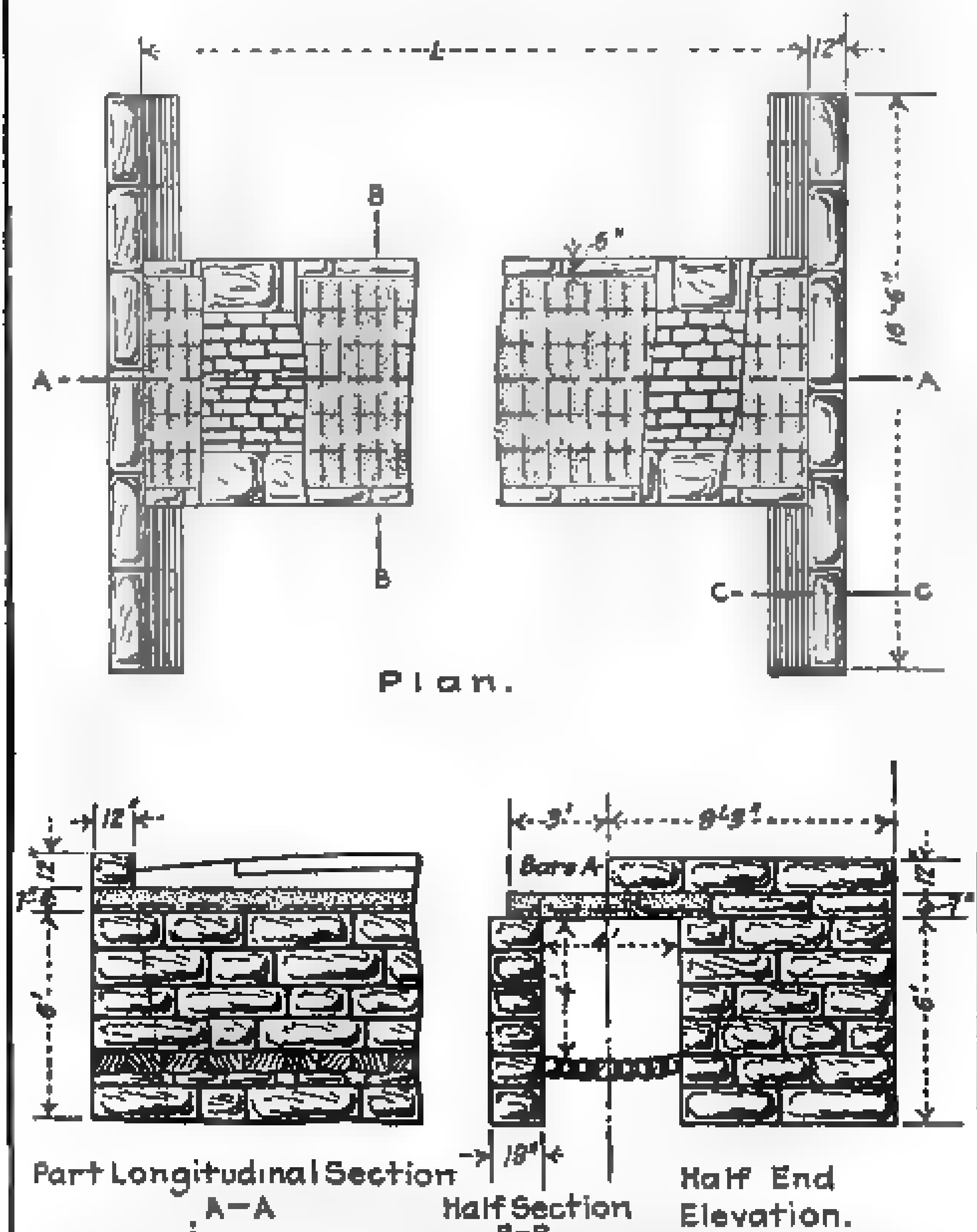
Mark	Position	No	Size	Length	Weight	Remarks
A	Transverse Barrel	22	½" Sq.	4'-10"	90 lb	
B	Longitud. Barrel	4	"	28'-6"	97 "	Continued into Wings
B	Longitud. Barrel	1	"	21'-6"	18 "	Center Bar
C	Transverse Floor	12	"	2'-3"	23 "	
D	Longitud. Floor	4	"	23'-0"	78 "	Cut in Field per Sketch
E	Vertical Wings	8	"	5'-6"	38 "	Continued into Wings
F	Horizont. Parapet	2	"	5'-6"	9 "	
G	Horizont. Footings	4	"	4'-0"	14 "	
	Total Reinforcing Steel				367 lb	

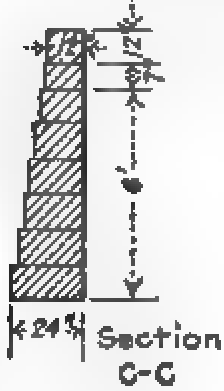


Elevation of Wing.

Note: { *For each additional Foot of Barrel use one additional Bar "A", One Half Bar "C", increase Length of Bars "B" and "D" by One Foot*

PLATE 18.—TYPICAL MASONRY CULVERT. STATE OF NEW HAMPSHIRE.

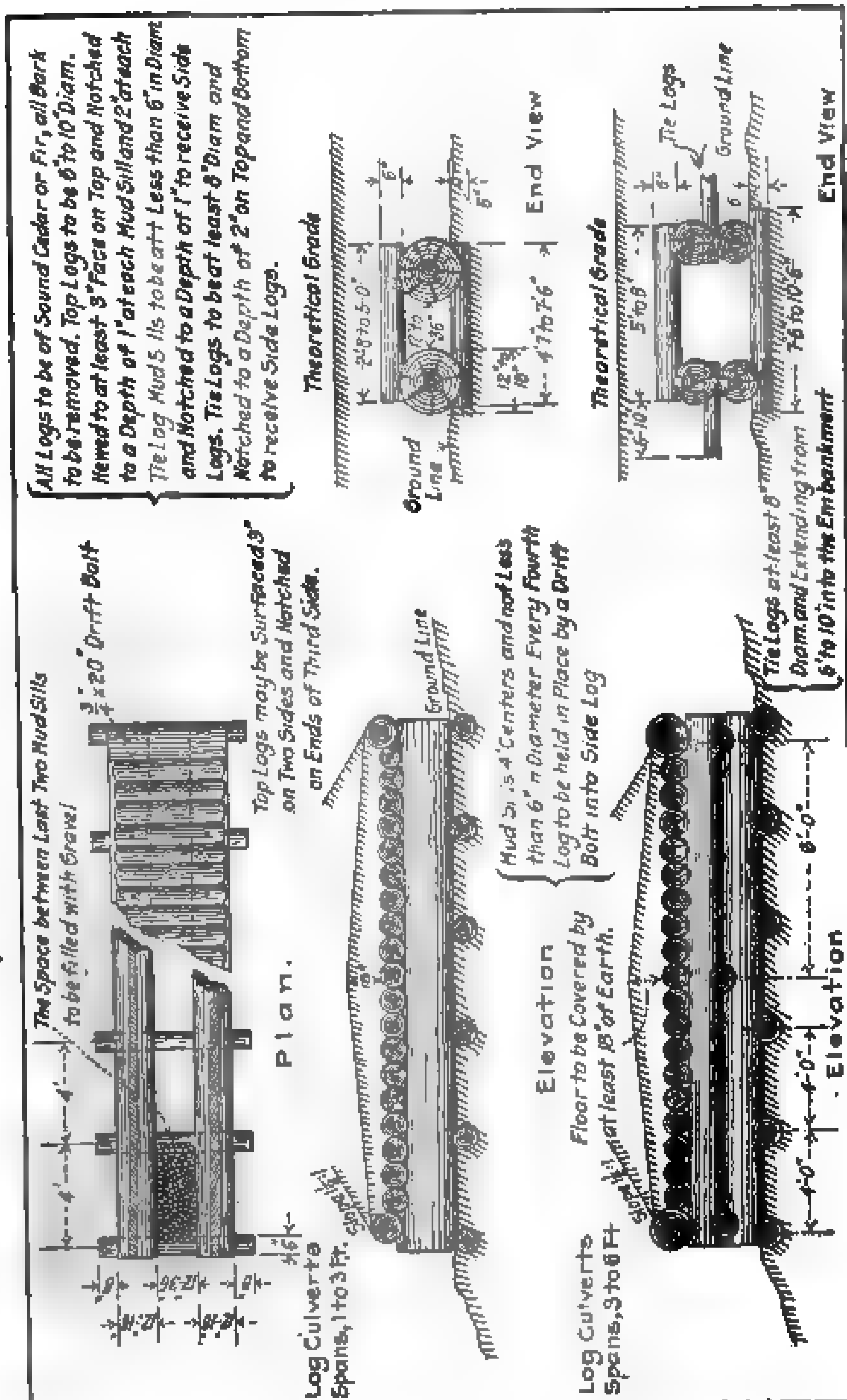




Depth Fill	Length L.	Bars A ½" Sq Spacing	Bars A ½" Sq Number	Bars A ½" Sq Length	Masonry Cu Yds	Concrete Cu. Yds	Paving
1	21'-0"	7"	40	5'-9"	24 3	3 0	10 2
2	21' 6"	6 ½"	43	"	24.6	3.0	10.4
3	24'-6"	7 ½"	43	"	26.6	3 4	11.8
4	27'-6"	7"	51	"	26.6	9 8	13.1
5	30' 6"	7"	56	"	30.6	4.2	14.4
6	33'-6"	6 ½"	66	"	32.6	4 6	15.8
8	39' 6"	6"	89	"	36.6	5.4	18.4

TABLE OF QUANTITIES 4'x4' CULVERT

PLATE 19.—TYPICAL LOG CULVERTS PIONEER ROADS.



Baker's Foundations

Rock (poor)	5 tons per square foot
" (solid & first quality)	25 " " " "
Dry clay	4 " " " "
Medium dry clay	2½ " " " "
Soft clay	1 ton " " "
Cemented gravel	8 tons " " "
Compact sand	4 " " " "
Clean dry sand	2 " " " "
Quick sand and alluvial soil	½ ton " " "

Where piles are used for types of construction where slight settlement is not objectionable a loading of from 10 to 15 tons for a sound well driven pile is conservative practice.

The safe load for a timber pile driven with a gravity hammer can be figured from the following simple formula. (Iowa Bridge Specifications.)

$$\text{Safe load in lb.} = \frac{2Wh}{s+1}$$

W = weight of hammer in lb.
H = fall in feet
S = average penetration in inches per blow for the last three blows.

Scour.—Scour is produced in different soils at approximately the following stream velocities.

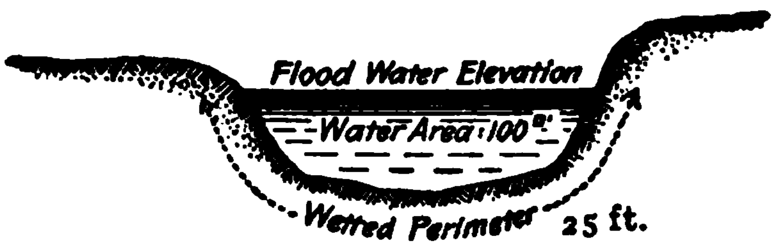
Sand	2 to 3 ft. per second
Loam	2 to 3½ " " "
Firm gravel	5 to 6 " " "

Riprap protection reduces scour. According to Trautwine a velocity of 8 miles per hour or 12′ per second will not derange quarry rubber stones exceeding ½ cu. ft. deposited around piers or abutments. If the natural stream velocity is not over 10 ft. per second the span is usually regulated so that the velocity under the bridge during freshets will not exceed 10′ per second. If the natural stream velocity of flow at the bridge site is not known it can be approximated roughly for small streams by the formula.

$$V = C\sqrt{RS}$$

Where V = Velocity of flow in feet per second
C = Constant assumed value 60
R = Hydraulic radius $\dfrac{\text{Cross sectional area of flow}}{\text{Wetted perimeter}}$
S = Slope of stream

Example.—To approximate the freshet velocity of the stream shown having a fall of 1.0′ per 100′ or 53 feet per mile.



$$V = C\sqrt{RS}$$
$$C = 60$$
$$R = \frac{100}{25} = 4$$
$$S = \frac{1}{100} = 0.01$$
$$V = 60\sqrt{4 \times 0.01} = 60\sqrt{0.04} = 60 \times 0.2 = 12 \text{ ft. per second.}$$

Where much ice occurs piers in small streams should be avoided. They can be used to advantage to reduce cost however if there is no danger of ice or débris jams particularly if the flow is sluggish and in the latter case for wide shallow streams the trestle design is economical.

Paved Fords.—For wide shallow arroyos of the arid regions of the west paved fords are in general use. These channels only carry water during sudden severe storms and it would be practically prohibitive in cost to provide large enough structures

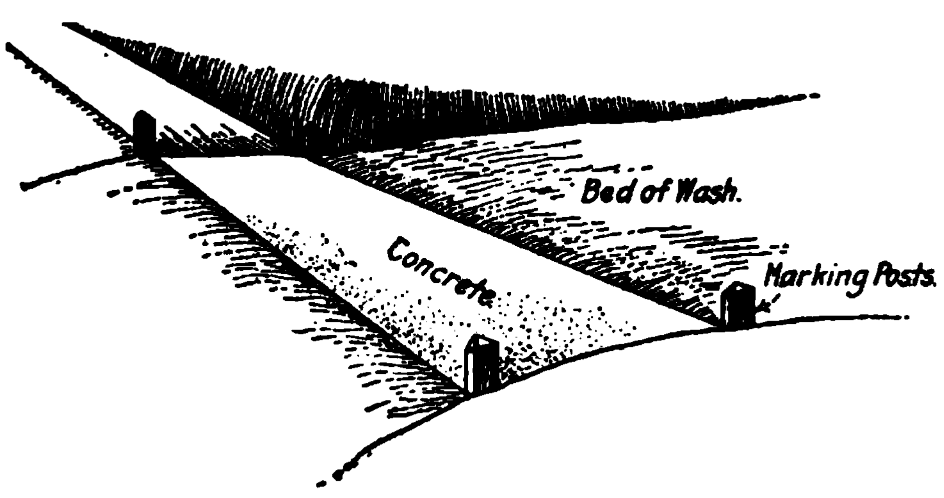


FIG. 23.—Paved ford.

to carry the sudden large infrequent flows. The road across an arroyo is kept slightly below the natural elevation of the wash and is paved with concrete, cobblestone or timber (see sketch). The alignment is straight and the location of the pavement is shown during flood by 4 marking posts 2 at each end which also indicate the depth of water so that it can be used even if covered with water unless the depth is too great for safety which can be determined by the gauges on the range posts. As the concrete is below the bottom of the stream no scour occurs and generally a thin layer of sand is deposited on the concrete which can be easily cleaned off with a road machine.

Plate 20.—(*Continued*)

Material for Pile Abutment

Name	Roadway	Quantity	Size	Length or Kind
Piling	16′ 18′	6	12″ butt dia.	10′-0″ in ground
Cap	Any	1	12″ × 12″	24′-0″
Backing	Any	6 or more	3″ × 12″	12′-0″
Backing	Any	6 or more	3″ × 12″	16′-0″
Drifts	Any	6	¾″ φ	2′-0″
Nails for backing plk.	Any	7½#	60d.	Steel wire nails

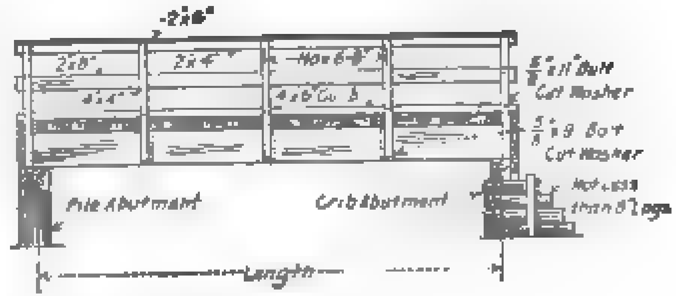
Maximum Length C. to C.	Roadway 16′-0″	Roadway 18′-0″	Roadway 20′-0″	Maximum Wheel Load Assumed on 2 Joists
24′-6″	9—4″ × 18″	10—4″ × 18″	11—4″ × 18″	3600#
22′-0″	9—4″ × 16″	10—4″ × 16″	11—4″ × 16″	5000#
19′-3″	9—4″ × 14″	10—4″ × 14″	11—4″ × 14″	4350#
16′-9″	9—4″ × 12″	10—4″ × 12″	11—4″ × 12″	3700#
19′-3″	9—3″ × 16″	10—3″ × 16″	11—3″ × 16″	4250#
16′-9″	9—3″ × 14″	10—3″ × 14″	11—3″ × 14″	3750#
14′-6″	9—3″ × 12″	10—3″ × 12″	11—3″ × 12″	3000#
Unit Load: 100# per sq. foot + 25% impact				Impact 25% allowed for

3″ × 12″ Floor (assumed worn to 2″) Good for 1600# Conc. Load
4″ × 12″ Floor (assumed worn to 3″) Good for 3600# Conc. Load

Bill of Lumber
For Light Wooden Bridges 16' to 25' Long. 16'-18'-20' Roadway.
Capacity: 100# Per Sq. Foot + 25% Impact

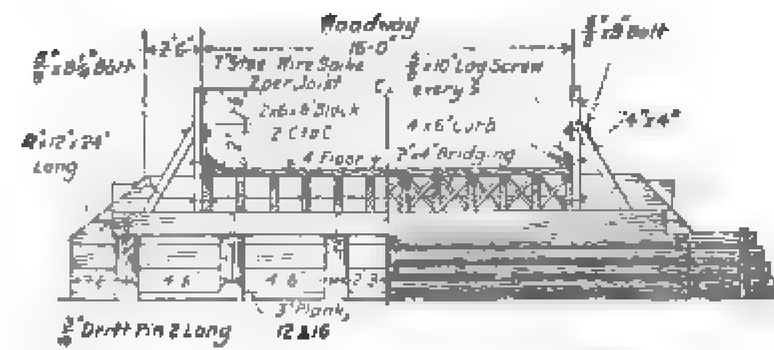
Name	Maximum Spans for Joists Shown: 25'-0" E. to E., 24'-0" C. to C.	23'-0" E. to E., C. to C.	20'-0" E. to E., 19'-0" C. to C.	18'-0" E. to E., 16'-9" C. to C.	16'-0" E. to E., 14'-6" C. to C.
			16'-0" Roadway		
Joists	9—4"×18"×25'	9—4"×16"×23'	9—3"×16"×20' or 9—4"×14"×20'	9—3"×14"×18' or 9—4"×12"×18'	9—3"×12"×16'
Floor	27—3"×12"×16' or 27—4"×12"×16'	25—3"×12"×16' or 25—4"×12"×16'	22—3"×12"×16' or 22—4"×12"×16'	20—3"×12"×16' or 20—4"×12"×16'	18—3"×12"×16' or 18—4"×12"×16'
Bridging	3—2"×4"×16'	3—2"×4"×16'	2—2"×4"×16'	2—2"×4"×16'	2—2"×4"×16'
			18'-0" Roadway		
Joists	10—4"×18"×25'	10—4"×16"×23'	10—3"×16"×20' or 10—4"×14"×20'	10—3"×14"×18' or 10—4"×12"×18'	10—3"×12"×16'
Floor	27—3"×12"×18' or 27—4"×12"×18'	25—3"×12"×18' or 25—4"×12"×18'	22—3"×12"×18' or 22—4"×12"×18'	20—3"×12"×18' or 20—4"×12"×18'	18—3"×12"×16' or 18—4"×12"×16'
Bridging	4—2"×4"×14'	4—2"×4"×14'	3—2"×4"×12'	3—2"×4"×12'	3—2"×4"×12'
			20'-0" Roadway		
Joists	11—4"×18"×25'	11—4"×16"×23'	11—3"×16"×20' or 11—4"×14"×20'	11—3"×14"×18' or 11—4"×12"×18'	11—3"×12"×16'
Floor	27—3"×12"×20' or 27—4"×12"×20'	25—3"×12"×20' or 25—4"×12"×20'	22—3"×12"×20' or 22—4"×12"×20'	20—3"×12"×20' or 20—4"×12"×20'	18—3"×12"×20' or 18—4"×12"×20'
Bridging	4—2"×4"×16'	4—2"×4"×16'	3—2"×4"×14'	3—2"×4"×14'	3—2"×4"×14'
			Any Roadway		
Curb	3—4"×6"×16'	3—4"×6"×16'	3—4"×6"×14'	2—4"×6"×18'	2—4"×6"×16'
Rail S.4S	5—4"×4"×16' 4—2"×4"×14' 4—2"×6"×14' 4—2"×8"×14'	5—4"×4"×16' 4—2"×4"×12' 4—2"×6"×12' 4—2"×8"×12'	4—4"×4"×16' 2—2"×4"×20' 2—2"×6"×20' 2—2"×8"×20'	4—4"×4"×18' 2—2"×4"×18' 2—2"×6"×18' 2—2"×8"×18'	4—4"×4"×16' 2—2"×4"×16' 2—2"×6"×16' 2—2"×8"×16'
Blocks	27—2"×6"×6"	25—2"×6"×6"	22—2"×6"×6"	20—2"×6"×6"	18—2"×6"×6"

PLATE 21.—STANDARD WOODEN BRIDGES. STATE OF WYOMING.



Note.
Paint Rails and Posts with Two Coats of White Lead

Side Elevation.



Half Section Pile Abutment. Half Section Crib Abutment

BILL OF MISCELLANEOUS MATERIAL

FOR STANDARD WOODEN BRIDGES 8' TO 20' LONG. 16'-18'-20' ROADWAY.
CAPACITY: 20-TON TRACTION ENG. (¾ ON REAR AXLE) + 25% IMPACT

Name	Road-way	Maximum Spans of Joists				
		20'-0" E. to E. 19'-0" C. to C.	16'-0" E. to E. 15'-0" C. to C.	12'-0" E. to E. 11'-0" C. to C.	10'-0" E. to E. 9'-0" C. to C.	8'-0" E. to E. 7'-0" C. to C.
Bridging nails	Any	6#—10d	6#—10d	4#—10d	4#—10d	
Rail nails	Any	5#—40d	4#—40d	3#—40d	3#—40d	2#—40d
Floor spikes	16	80#—7"	64#—7"	48#—7"	40#—7"	32#—7"
Floor spikes	18	80#—7"	64#—7"	48#—7"	40#—7"	32#—7"
Floor spikes	20	88#—7"	70#—7"	53#—7"	44#—7"	35#—7"
Curb lag screws	Any	10—⅝"×10"	8—⅝"×10"	6—⅝"×10"	6—⅝"×10"	6—⅝"×10"
Rail bolts	Any	12—⅝"×9"	12—⅝"×9"	10—⅝"×9"	10—⅝"×9"	8—⅝"×9"
Rail bolts	Any	8—⅝"×11"	8—⅝"×11"	6—⅝"×11"	6—⅝"×11"	4—⅝"×11"
Rail bolts	Any	4—⅝"×8¼"	4—⅝"×8¼"	4—⅝"×8¼"	4—⅝"×8¼"	4—⅝"×8¼"
Pressed washers	Any	64 for ⅝" bolts	62 for ⅝" bolts	50 for ⅝" bolts	50 for ⅝" bolts	42 for ⅝" bolts

ALL NAILS AND SPIKES TO BE STEEL WIRE

PLATE 21.—(*Continued*)

MATERIAL FOR ONE PILE ABUTMENT

Name	Roadway	Quantity	Size	Length or Kind
Piling	16'–18'	6	12" butt dia.	10'–0" in ground
Cap	Any	1	12" × 12"	24'–0"
Backing	Any	6 or more	3" × 12"	12'–0"
Backing	Any	6 or more	3" × 12"	16'–0"
Drifts	Any	6	¾" φ	2'–0"
Nails for backing plk.	Any	7½#	60d	Steel wire nails

Maximum Length C. to C.	Roadway		
	16'–0"	18'–0"	20'–0"
20'–0"	12—4" × 18"	12—4" × 18"	14—4" × 18"
16'–0"	12—4" × 16"	12—4" × 16"	14—4" × 16"
12'–0"	12—4" × 14"	12—4" × 14"	14—4" × 14"
11'–9"	12—3" × 16"	12—3" × 16"	14—3" × 16"
9'–0"	12—3" × 14"	12—3" × 14"	14—3" × 14"
8'–9"	12—4" × 12"	12—4" × 12"	14—4" × 12"
6'–6"	12—3" × 12"	12—3" × 12"	14—3" × 12"

Plate 21.—(*Continued*)

Bill of Lumber

For Standard Wooden Bridges 8′ to 20′ Long. 16′–18′–20′ Roadway.
Capacity: 20-ton Traction Eng. (¾ on Rear Axle) + 25 % Impact

Name	Maximum Spans for Joists Shown				
	20′–0″ E. to E. 19′–0″ C. to C.	16′–0″ E. to E. 15′–0″ C. to C.	12′–0″ E. to E. 11′–0″ C. to C.	10′–0″ E. to E. 9′–0″ C. to C.	8′–0″ E. to E. 7′–0″ C. to C.
16′–0″ Roadway					
Joists	12—4″ × 18″ × 20′	12—4″ × 16″ × 16′	12—3″ × 16″ × 12′ or 12—4″ × 14″ × 12′	12—3″ × 14″ × 10′ or 12—4″ × 12″ × 10′	12—3″ × 12″ × 8′
Floor	22—4″ × 12″ × 16′	18—4″ × 12″ × 16′	14—4″ × 12″ × 16′	11—4″ × 12″ × 16′	9—4″ × 12″ × 16′
Bridging	9—2″ × 4″ × 16′	9—2″ × 4″ × 16′	5—2″ × 4″ × 16′	5—2″ × 4″ × 16′	
18′–0″ Roadway					
Joists	12—4″ × 18″ × 20′	12—4″ × 16″ × 16′	12—3″ × 16″ × 12′ or 12—4″ × 14″ × 12′	12—3″ × 14″ × 10′ or 12—4″ × 12″ × 10′	12—3″ × 12″ × 8′
Floor	22—4″ × 12″ × 18′	18—4″ × 12″ × 18′	14—4″ × 12″ × 18′	11—4″ × 12″ × 18′	9—4″ × 12″ × 18′
Bridging	10—2″ × 4″ × 16′	10—2″ × 4″ × 16′	6—2″ × 4″ × 16′	6—2″ × 4″ × 16′	
20′–0″ Roadway					
Joists	14—4″ × 18″ × 20′	14—4″ × 16″ × 16′	14—3″ × 16″ × 12′ or 14—4″ × 14″ × 12′	14—3″ × 14″ × 10′ or 14—4″ × 12″ × 10′	14—3″ × 12″ × 8′
Floor	22—4″ × 12″ × 20′	18—4″ × 12″ × 20′	14—4″ × 12″ × 20′	11—4″ × 12″ × 20′	9—4″ × 12″ × 20′
Bridging	12—2″ × 4″ × 16′	12—2″ × 4″ × 16′	7—2″ × 4″ × 16′	7—2″ × 4″ × 16′	
Any Roadway					
Curb	3—4″ × 6″ × 14′	2—4″ × 6″ × 16′	2—4″ × 6″ × 12′	2—4″ × 6″ × 10′	2—4″ × 6″ × 8′
Rail S. 4S.	4—4″ × 4″ × 16′ 2—2″ × 4″ × 20′ 2—2″ × 6″ × 20′ 2—2″ × 8″ × 20′	4—4″ × 4″ × 16′ 2—2″ × 4″ × 16′ 2—2″ × 6″ × 16′ 2—2″ × 8″ × 16′	3—4″ × 4″ × 16′ 2—2″ × 4″ × 12′ 2—2″ × 6″ × 12′ 2—2″ × 8″ × 12′	3—4″ × 4″ × 16′ 2—2″ × 4″ × 10′ 2—2″ × 6″ × 10′ 2—2″ × 8″ × 10′	2—4″ × 4″ × 16′ 2—2″ × 4″ × 8′ 2—2″ × 6″ × 8′ 2—2″ × 8″ × 8′
Blocks	22—2″ × 6″ × 6″	18—2″ × 6″ × 6″	14—2″ × 6″ × 6″	12—2″ × 6″ × 6″	10—2″ × 6″ × 6″

PLATE 22.—30′ SPAN KING POST TIMBER BRIDGE. STATE OF WYOMING.

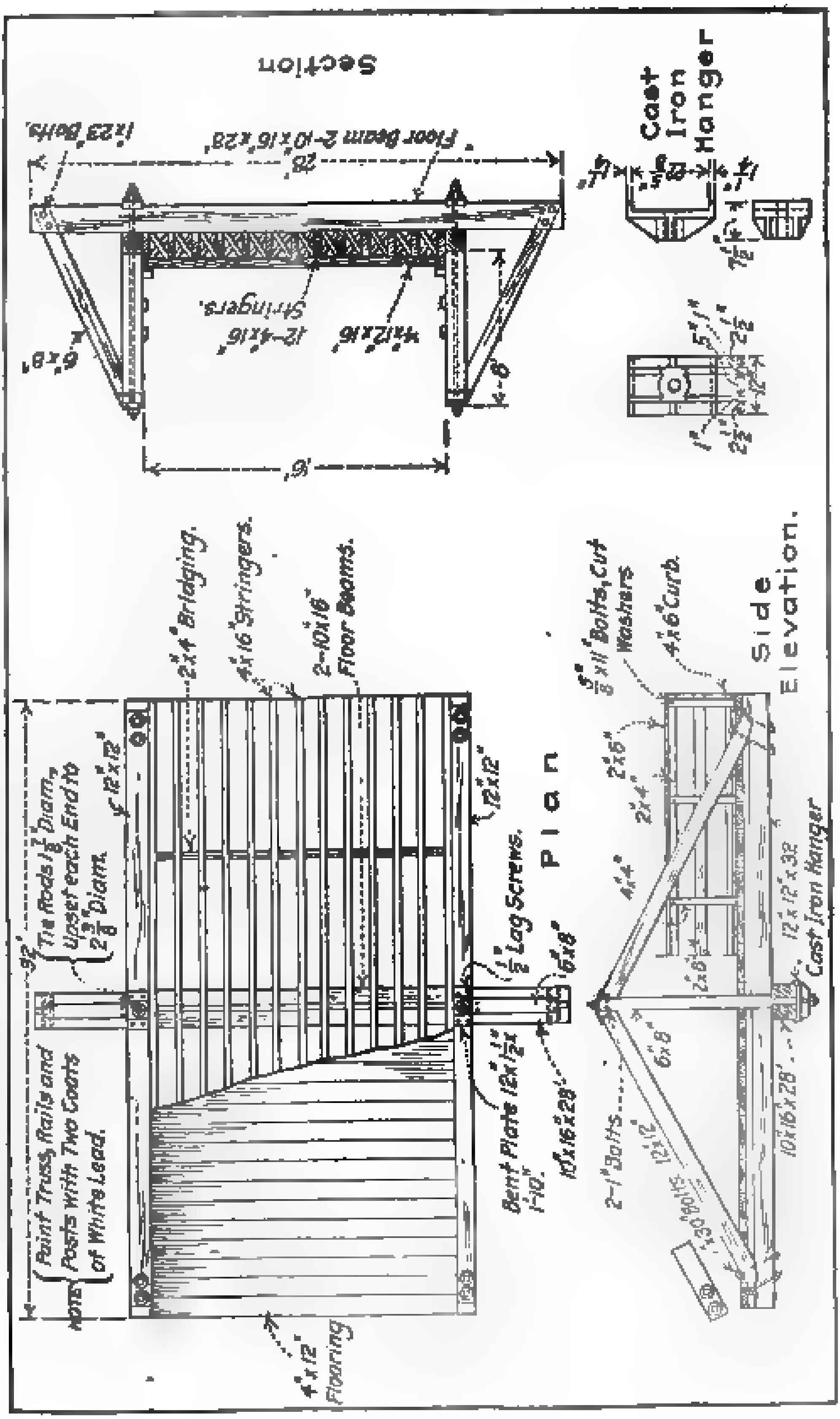
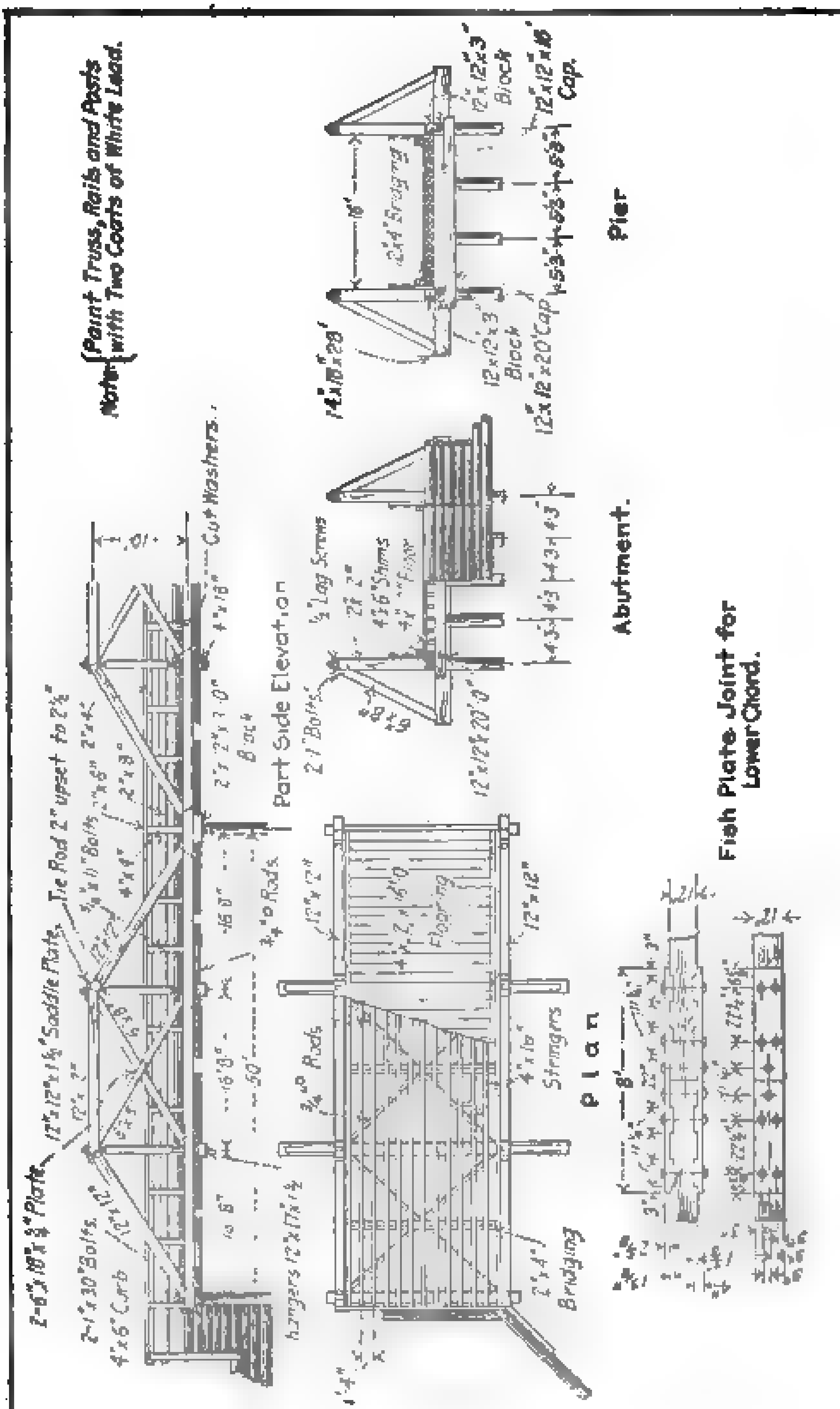


PLATE 23.—TYPICAL 50' SPAN PONY TRUSS TIMBER BRIDGE. STATE OF WYOMING.



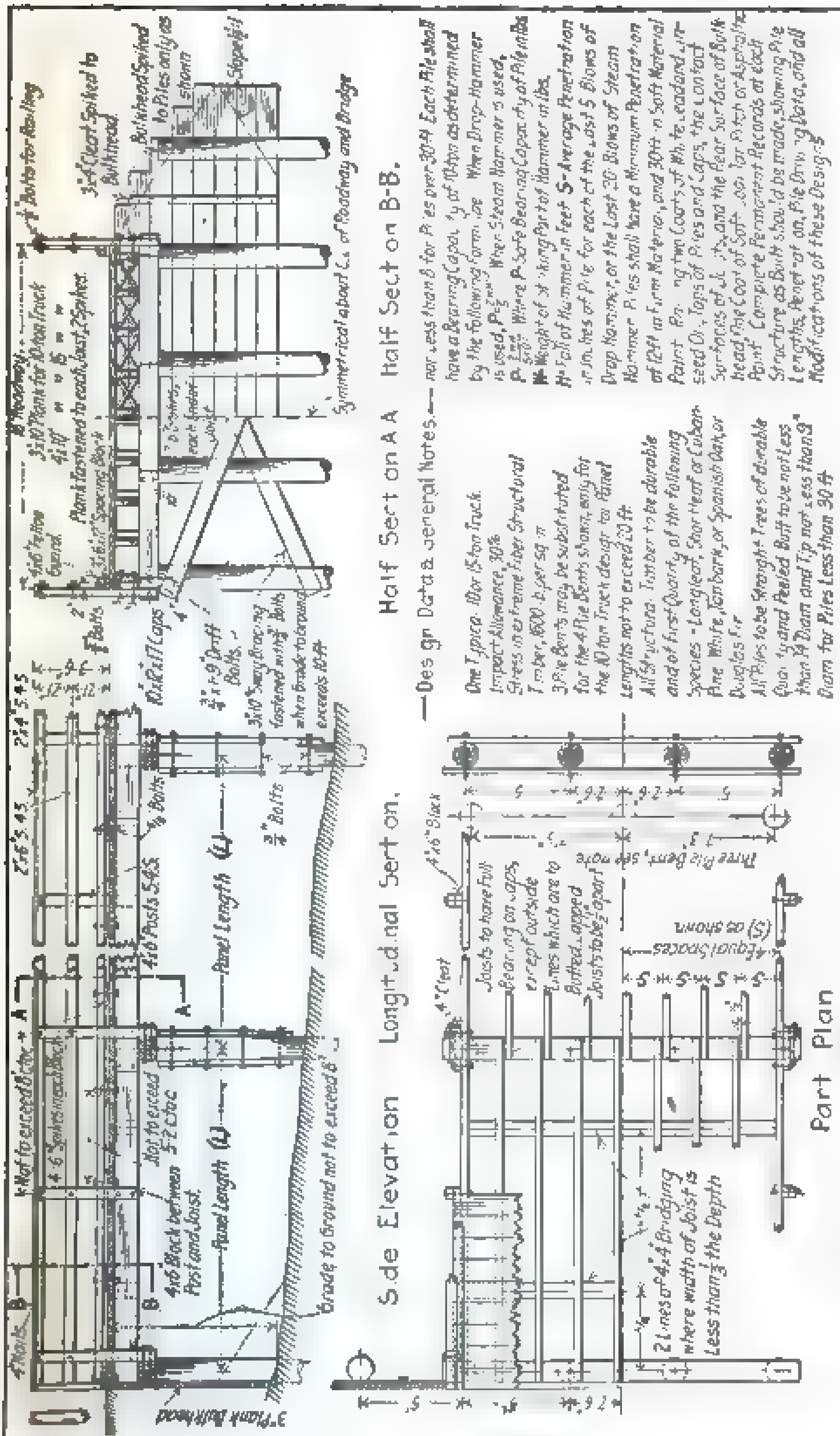


PLATE 24.—TYPICAL PILE TRESTLE. U. S. OFFICE OF PUBLIC ROADS.

PLATE 24.—(*Continued*)

DIMENSIONS AND QUANTITIES FOR SUPERSTRUCTURE

CAPACITY 15-TON TRUCK

Panel Length (L)	Intermediate Panel				
	Size of Joists	Joists	Floor Railing Details	Total Lumber	Bolts, Washers, Spikes, Nails
Feet	Inches	Ft. B. M.	Ft. B. M.	Ft. B. M.	Pounds
10	6×12	590	800	1390	80
	4×14	460	840	1300	
11	6×12	650	870	1520	90
	4×14	500	920	1420	
12	6×12	700	940	1640	90
	4×16	620	990	1610	
	8×12	1010	1020	2030	
13	6×14	880	1020	1900	90
	4×16	670	1070	1740	
	8×12	1080	1090	2170	
14	6×14	950	1090	2040	90
	4×16	720	1140	1860	
15	8×12	1150	1170	2320	100
	6×14	1010	1170	2180	
16	10×12	1530	1240	2770	
	6×14	1070	1240	2310	100
	6×16	1230	1240	2470	
17	10×12	1620	1340	2960	
	8×14	1510	1340	2850	120
	6×16	1300	1340	2640	
18	10×12	1710	1410	3120	
	8×14	1600	1410	3010	130
	6×16	1370	1410	2780	
19	10×12	1800	1490	3290	
	8×14	1680	1490	3170	130
	6×16	1440	1490	2930	
20	8×14	1760	1560	3320	130
	8×16	2020	1560	3580	
21	10×14	2310	1640	3950	140
	8×16	2110	1640	3750	
22	10×14	2410	1710	4120	150
	8×16	2210	1710	3920	

Plate 24.—(*Continued*)

Capacity 10-Ton Truck

Panel Length (L)	Size of Joists	Intermediate Panel: Joists	Intermediate Panel: Floor Railing Details	Intermediate Panel: Total Lumber	Intermediate Panel: Bolts, Washers, Spikes, Nails
Feet	Inches	Ft. B. M.	Ft. B. M.	Ft. B. M.	Pounds
10	4×12	400	640	1040	70
	3×14	350	680	1030	
11	4×12	430	700	1130	80
	3×14	380	740	1120	
12	6×12	700	760	1460	80
	3×14	410	800	1210	
13	6×12	760	810	1570	80
	4×14	590	860	1450	
14	6×12	810	870	1680	
	4×14	630	910	1540	90
	4×16	720	910	1630	
15	6×12	860	930	1790	
	4×14	670	970	1640	90
	4×16	770	970	1740	
16	6×12	920	990	1910	
	6×14	1070	990	2060	100
	4×16	820	1030	1850	
17	6×12	970	1070	2040	
	6×14	1130	1070	2200	110
	4×16	870	1110	1980	
18	8×12	1370	1130	2500	
	6×14	1200	1130	2330	120
	4×16	910	1170	2080	
19	8×12	1440	1180	2620	
	6×14	1260	1180	2440	120
	4×16	960	1220	2180	
20	8×12	1510	1240	2750	
	6×14	1320	1240	2560	120
	6×16	1510	1240	2750	
21	10×12	1980	1300	3280	
	6×14	1390	1300	2690	130
	6×16	1580	1300	2880	
22	10×12	2070	1360	3430	
	8×14	1930	1360	3290	130
	6×16	1660	1360	3020	
23	10×12	2160	1420	3580	
	8×14	2020	1420	3440	130
	6×16	1730	1420	3150	
24	10×12	2250	1470	3720	
	8×14	2100	1470	3570	130
	6×16	1800	1470	3270	
25	10×14	2730	1560	4290	
	8×14	2180	1560	3740	150
	6×16	1870	1560	3430	
26	10×14	2840	1610	4450	160
	8×16	2600	1610	4210	
27	10×14	2940	1670	4610	160
	8×16	2690	1670	4360	
28	10×14	3050	1730	4780	160
	8×16	2780	1730	4510	
29	10×14	3150	1790	4940	160
	8×16	2880	1790	4670	

Washers to be ogee type cast iron ⅝″ and ⅜″ bolts, and cut wrought iron or steel plate washers for ½″ bolts.

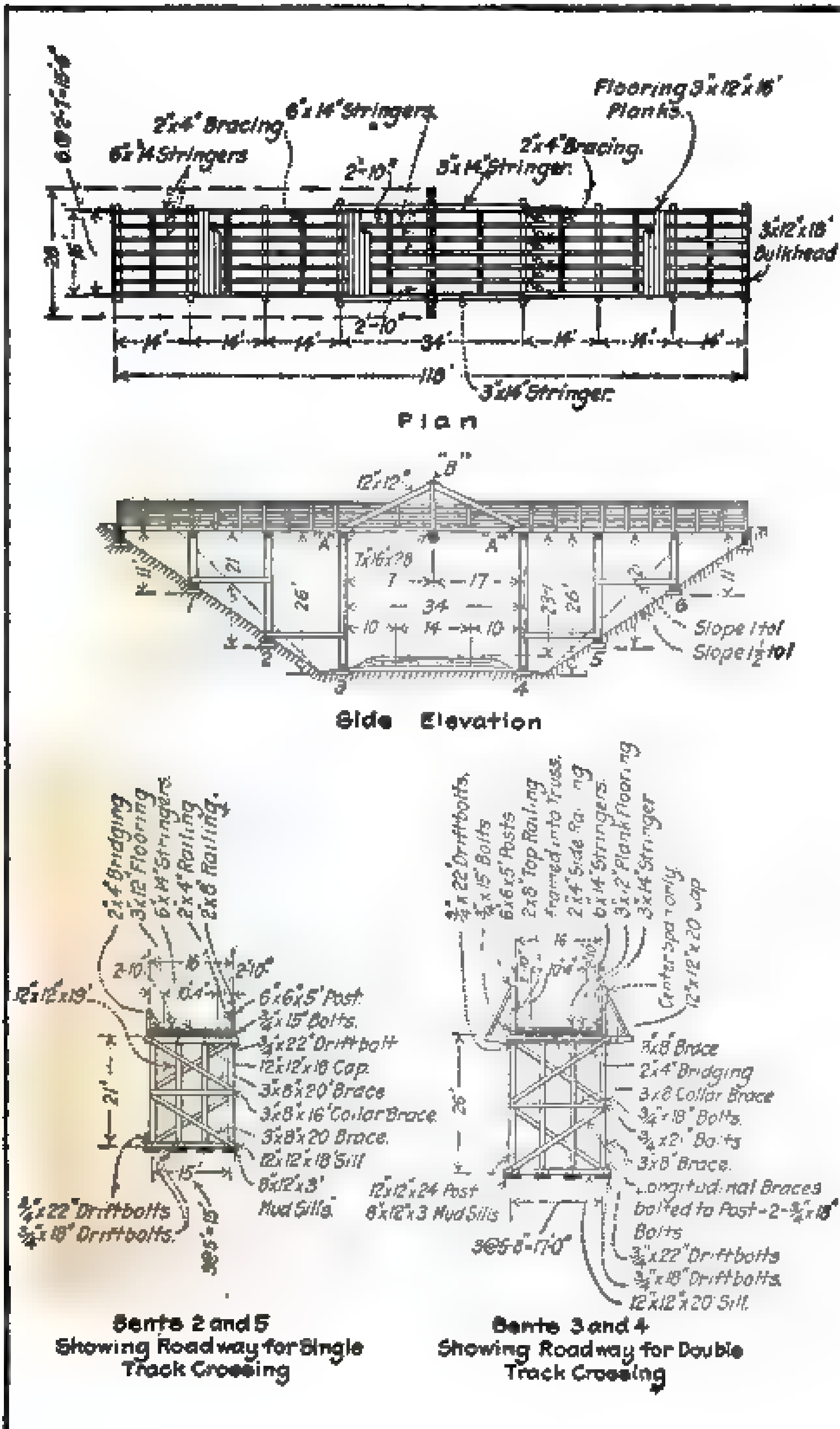
PLATE 24.—(*Continued*)

DIMENSIONS AND QUANTITIES—SUBSTRUCTURE

Grade to Ground	Sway Bracing—Intermediate Bent			
	Sets	Length	Lumber	Bolts
Feet	No. Reqd.	Feet	Ft. B. M.	Pounds
10–12	1	18	90	35
12–15	1	20	100	35
15–18	1	22	110	35
18–23	2	18 & 20	190	60
23–26	2	20	200	60
One cap 10″×12″×17′–0″			170	10

Grade to Ground	Bulkhead—End Bent	
	Lumber	Spikes
Feet	Ft. B. M.	Pounds
4	270	5
5	360	5
6	460	10
7	550	10
8	640	10

PLATE 25.—TYPICAL FRAMED TRESTLE. ILLINOIS CENTRAL RAILROAD.



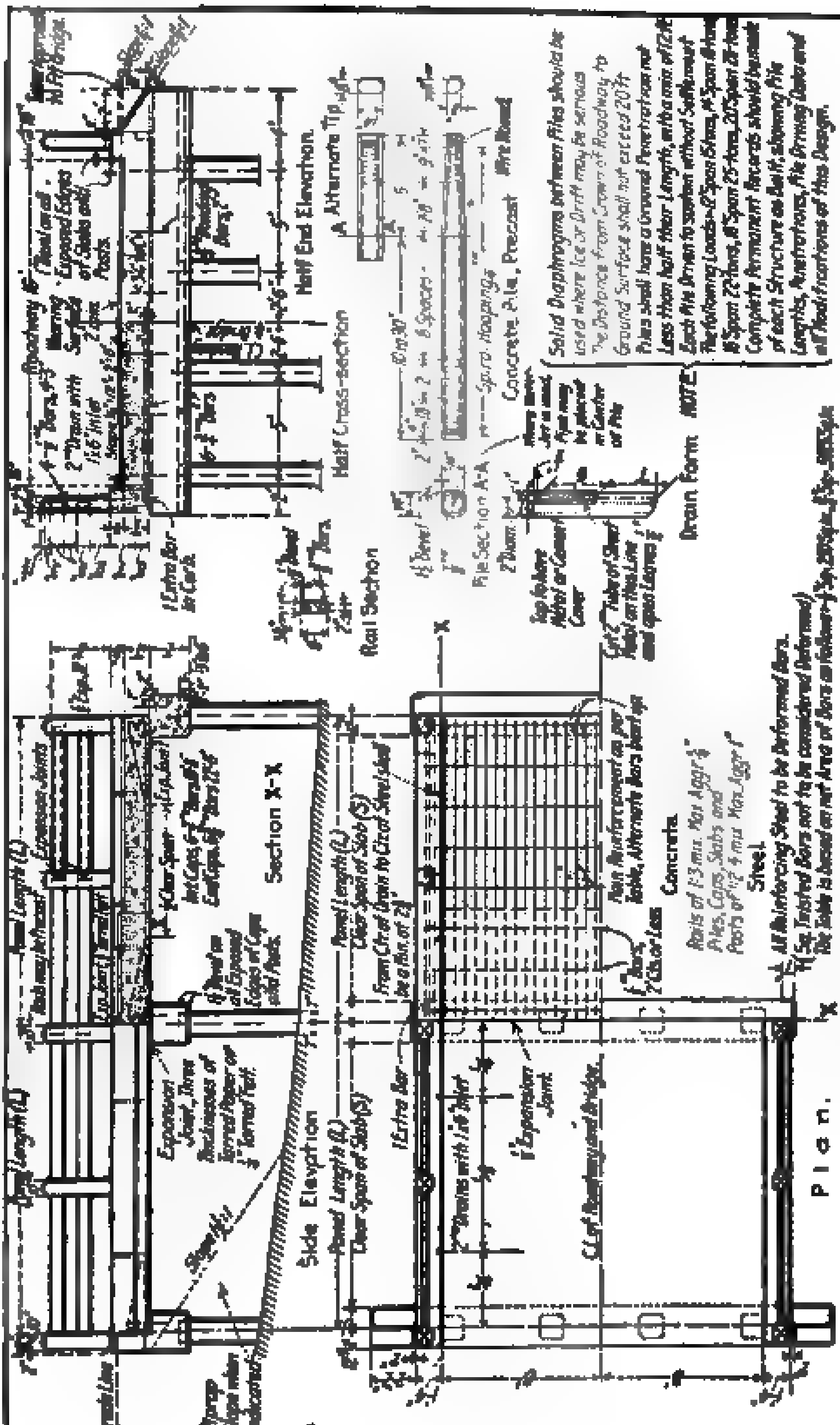


PLATE 26.—TYPICAL CONCRETE PILE TRESTLE. U. S. OFFICE OF PUBLIC ROADS.

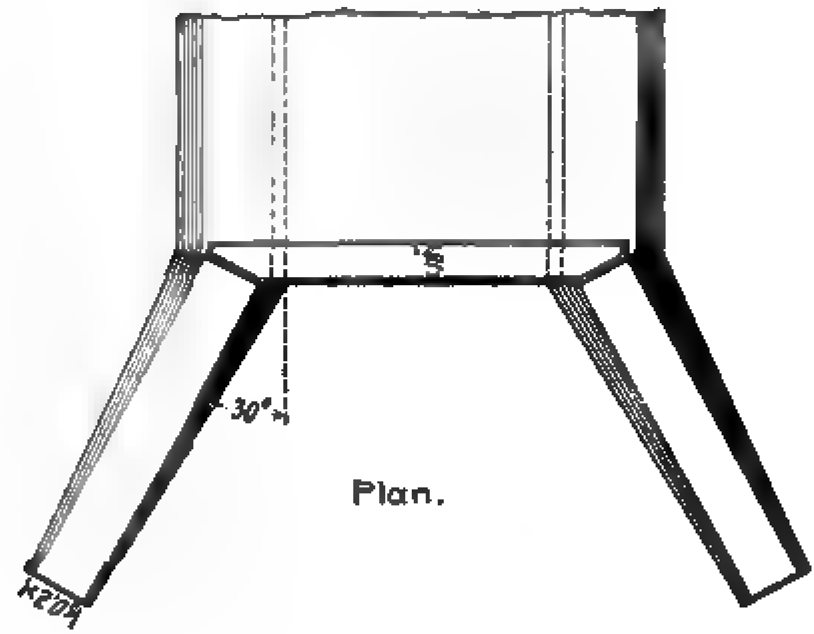
PLATE 26.—(*Continued*)

DIMENSIONS AND ESTIMATED QUANTITIES CONCRETE PILE AND SLAB TRESTLES

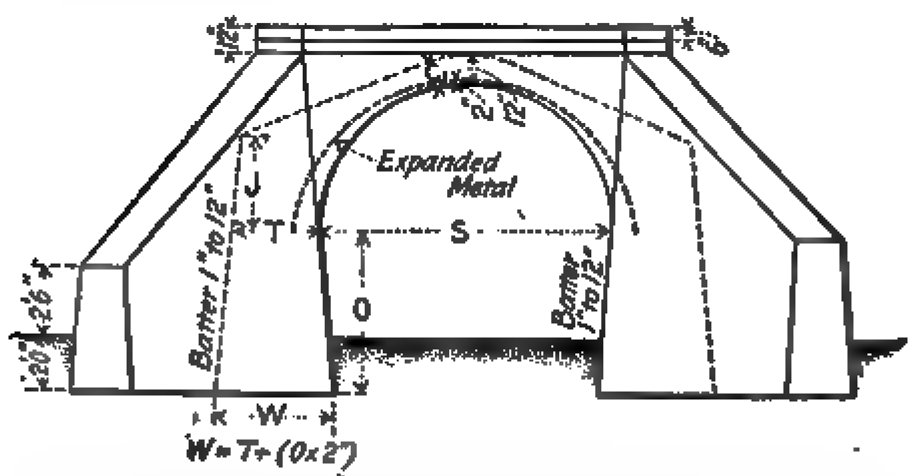
Item	Panel Length	Clear Span	Min. Slab Thickness	Reinforcing Steel	Intermediate Panel		End Panel	
					Concrete	Steel	Concrete	Steel
	L	S	T	Main Reinforcement	Cubic Yards	Pounds	Cubic Yards	Pounds
Slabs and curbs...	14 Ft.	12 Ft.	12½ In.	¾" sq. 7" ctrs.	11.46	1070	12 29	1070
	16 Ft.	14 Ft.	14 In.	¾" sq. 6" ctrs.	14.48	1370	15 40	1370
	18 Ft.	16 Ft.	16 In.	⅞" sq. 7½" ctrs.	18 38	1680	19 41	1680
	20 Ft.	18 Ft.	17½ In.	⅞" sq. 6½" ctrs.	22 14	2130	23.26	2130
	22 Ft.	20 Ft.	19½ In.	⅞" sq. 6" ctrs.	26 89	2460	28 13	2460
Railing........	One rail post				0 0762 Cu. Yd. Concr.		14 45 Lb. Steel	
	One rail (section 3½" × 8") per lin. ft.				0 0072 Cu. Yd. Concr.		1.913 Lb. Steel	
Bents............	One pile 15 feet long				0 67 Cu. Yd. Concr.		174 0 Lb. Steel	
	One pile (section 1'–2" × 1'–2") per lin. ft.				0 0504 Cu. Yd. Concr.		11.6 Lb. Steel	
	One cap for intermediate bent				2 82 Cu. Yd. Concr.		238.0 Lb. Steel	
	One cap for end bent with walls				3 55 Cu. Yd. Concr.		283.0 Lb. Steel	

DESIGN DATA:
Steel in tension, 16,000 lb. per sq. in.
Concrete in compression 600 lb. per sq. in.
Concentrated load, one 15-ton typical truck.
Impact allowance, 30%.
Paving not to exceed 120 lb. per sq. ft.

PLATE 27.



Plan.

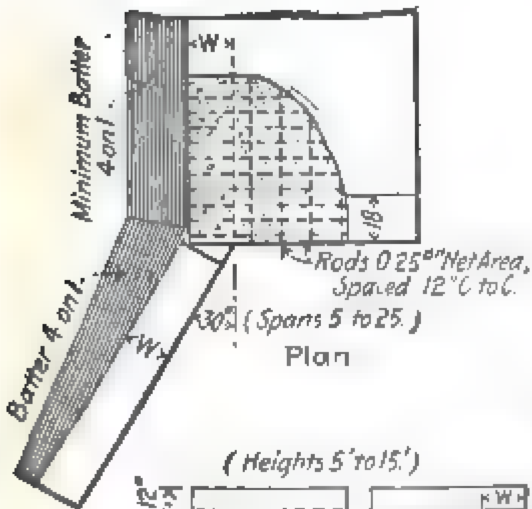


End Elevation.

GENERAL DIMENSIONS SEMI-CIRCULAR ARCH CULVERTS

S Span	Thickness at Springing Line		Thickness of Ring		Height of Haunch	
	T Concrete	K Masonry	C Concrete	R Masonry	J Concrete	V Masonry
6	2'-6"	2'-6"	10"	10"	1'-9"	2'-0"
[illegible]	2'-6"	2'-6"	11"	12"	2'-6"	2'-6"
10	3'-0"	3'-0"	12"	12"	3'-0"	3'-0"
12	3'-6"	3'-6"	14"	15"	3'-6"	3'-9"
14	3'-9"	3'-9"	15"	15"	4'-0"	4'-6"
16	4'-0"	4'-0"	16"	15"	4'-8"	5'-0"
18	4'-6"	4'-6"	18"	18"	5'-0"	5'-6"
20	5'-0"	5'-0"	18"	18"	5'-6"	6'-0"

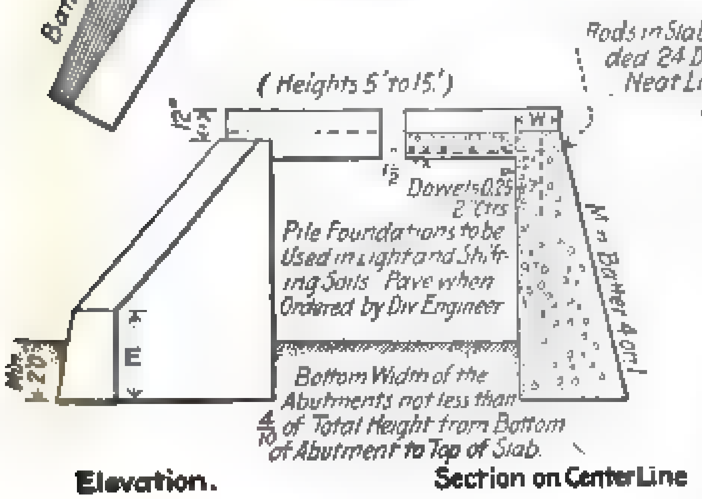
Plate 28.—New York State Slab Bridges.



Note

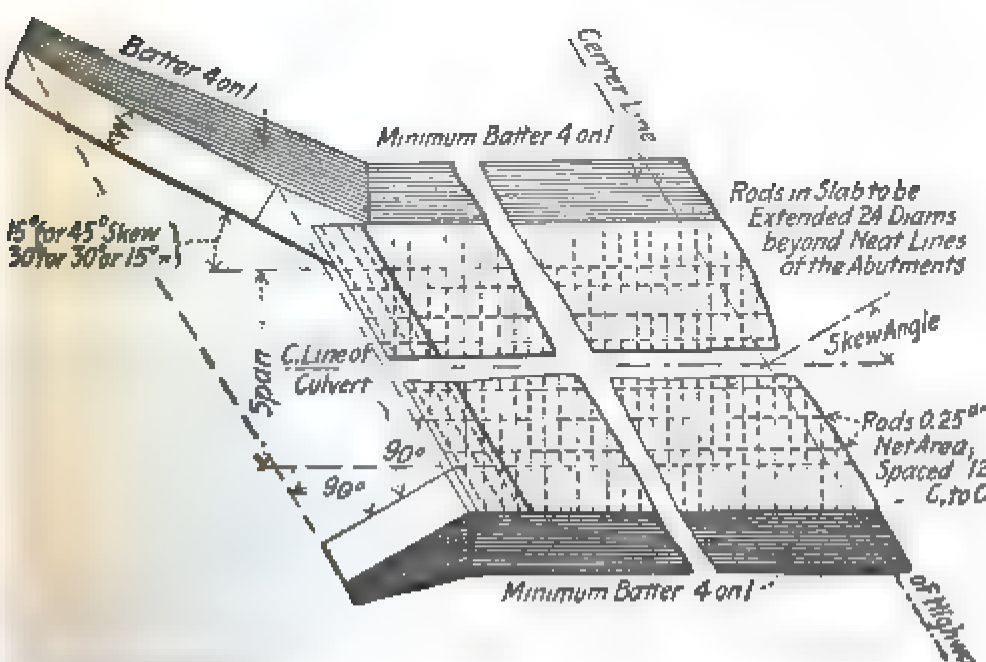
All rods to have a deformed cross-section. All rib metal to be of medium steel

2d class concrete in all slabs and parapets 3d class concrete in wings invert and abutments. Wing walls on the outlet end of all square culverts with concrete floors to be built parallel to the center line of the culvert. Round all exposed edges to 1½ inch radius.



For Typical Section "F"

Where culvert covers become a part of concrete base for brick pavement, transverse reinforcement should be extended 12" beyond back of abutment into concrete base.



Dimensions of slabs on page 118.

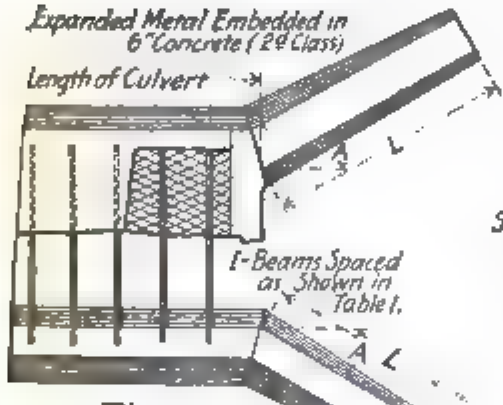
PLATE 28.—(*Continued*)

Span	Thickness of Slab*	Net Area of Rods	Rod Spacing C–C	Length of Dowels
5	8"	0.25sq."	4½"	12"
6	9"	"	4"	"
7	10"	0.39sq."	5¾"	"
8	10"	"	5¼"	"
9	11"	"	5"	"
10	12"	"	4¾"	"
11	12"	0.56sq."	6¼"	"
12	13"	"	6"	18"
13	13"	"	5¾"	"
14	14"	"	5⅜"	"
15	14"	"	5"	"
16	15"	"	4¾"	"
17	15"	"	4¾"	"
18	16"	"	4½"	"
19	17"	"	4¼"	"
20	18"	0.77sq."	5¼"	"
21	18"	"	5¼"	"
22	19"	"	5"	24"
23	19"	"	5"	"
24	20"	"	4⅝"	"
25	21"	1.00sq."	5⅞"	"

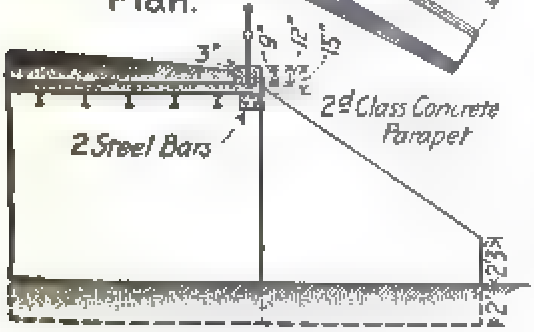
For Spans 5′ to 19′ W = 18" For Clear Height 10′ or less
" " 5′ to 19′ W = 24" " " " 11′ to 15′
" " 20′ to 25′ W = 24" " " " 15′ or less
For Clear Height 7′ or less E = 3′-0"
" " " 8′ to 10′ E = 4′-0"
" " " above 10′ E = 5′-0"

* NOTE.—The thickness of slab given is for shallow fills. For the effect of deep fills see Table 53A, page 565.

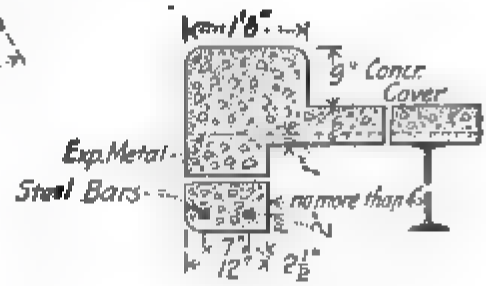
PLATE 29.—NEW YORK STATE I-BEAM BRIDGES.



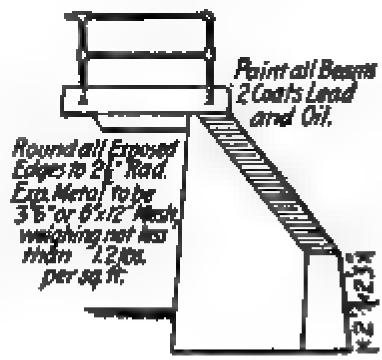
Plan.



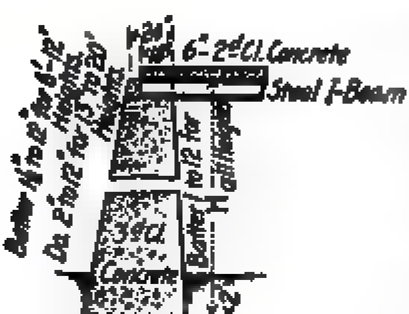
Longitudinal Section.



Cross Section of Parapet Showing Reinforcing.

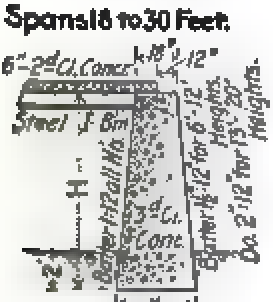


Part End Elevation.



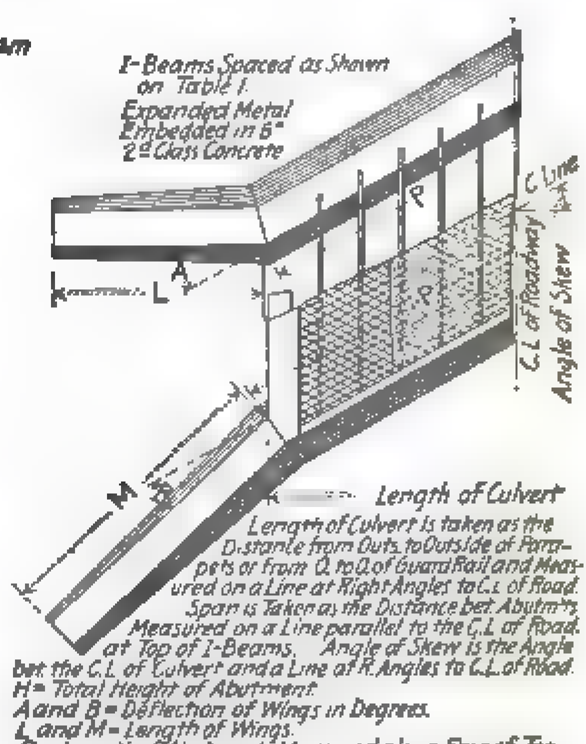
6' to 12' high, x=24"+(H×2½")
13' to 20' " , x=26"+(H×3")

Spans 18 to 30 Feet.



6' to 12' high, x=18"+(H×2½")
13' to 20' " , x=18"+(H×3")

Spans 6 to 17 Feet.



Skew Culvert.

PLATE 29.—(*Continued*)

Span, all Culverts	Opening at Right Angles to Faces of Abutments			Steel I-Beams					Steel Bars		Sq. feet E'x'p'dMet.		Cu. Yds. 2d Class Concrete Cover and Parapets		Ft. B. M. Lumber		Pounds Spikes and Nails	Lin. ft. Bridge Rail	Lin. ft. Pipe Rail
	15° Skew	30° Skew	45° Skew	Depth Inches	Spacing	Length feet	Wt. per ft.	Wt. of Beam	Size	Weight of 4 Bars	25 foot Length	Per foot Length	25 foot Length	Per foot Length	25 foot Length	Per foot Length			
6	5.80	5.20	4.24	6		8	12½	100	¾"	61	200	8	4.54	0.15	855	30	24	20	16
7	6.76	6.06	4.95	7		9	15	135	¾"	69	225	9	5.08	0.17	952	33	26	22	18
8	7.73	6.93	5.66	7		10	15	150	¾"	76	250	10	5.63	0.19	1042	36	28	24	20
9	8.69	7.79	6.36	8	2'-9"	11	18	198	¾"	84	275	11	6.63	0.20	1143	39	30	26	22
10	9.66	8.66	7.07	9	3'-0"	12	21	252	¾"	92	300	12	7.28	0.22	1234	42	32	28	24
11	10.63	9.53	7.78	9	3'-0"	13	21	273	⅞"	135	325	13	7.88	0.24	1325	45	34	30	26
12	11.59	10.39	8.49	9	2'-6"	14	21	294	⅞"	146	350	14	8.48	0.26	1431	48	36	32	28
13	12.56	11.26	9.19	10	3'-0"	15	25	375	1"	204	375	15	9.16	0.28	1523	51	38	34	30
14	13.52	12.12	9.90	10	2'-9"	16	25	400	1"	218	400	16	9.78	0.30	1633	54	40	36	32
15	14.49	12.99	10.61	12	3'-0"	17	31½	535½	1"	231	425	17	10.56	0.31	1727	57	42	38	34
16	15.45	13.86	11.31	12	3'-0"	18	31½	567	1"	245	450	18	11.19	0.33	1820	60	44	40	36
17	16.42	14.72	12.02	12	3'-0"	19	31½	598½	1⅛"	327	475	19	11.81	0.35	1956	63	46	42	38
18	17.39	15.59	12.73	12	3'-0"	21	31½	661½	1⅛"	361	525	21	12.90	0.39	2052	66	48	44	40
19	18.35	16.46	13.44	12	2'-9"	22	31½	693	1⅛"	378	550	22	13.51	0.41	2148	69	50	46	42
20	19.32	17.32	14.14	15	3'-0"	23	42	966	1⅛"	396	575	23	14.51	0.43	2244	72	52	48	44
21	20.28	18.19	14.85	15	3'-0"	24	42	1008	1⅛"	510	600	24	15.14	0.44	2340	75	54	50	46
22	21.26	19.05	15.56	15	3'-0"	25	42	1050	1⅛"	531	625	25	15.79	0.46	2519	78	56	52	48
23	22.22	19.92	16.26	15	3'-0"	26	42	1092	1⅛"	552	650	26	16.43	0.48	2618	81	58	54	50
24	23.18	20.78	16.97	15	3'-0"	27	42	1134	1⅛"	694	675	27	17.08	0.50	2718	84	60	56	52
25	24.15	21.65	17.68	15	2'-9"	28	42	1176	1⅛"	720	700	28	17.72	0.52	2818	87	62	58	54
26	25.11	22.52	18.38	15	2'-6"	29	42	1218	1⅛"	887	725	29	18.36	0.54	2918	90	64	60	56
27	26.08	23.38	19.09	18	3'-0"	30	55	1650	1⅛"	918	750	30	19.50	0.56	3018	93	66	62	58
28	27.05	24.25	19.80	18	3'-0"	31	55	1705	1⅛"	949	775	31	20.16	0.57	3222	96	68	64	60
29	28.01	25.11	20.51	18	3'-0"	32	55	1760	1⅛"	979	800	32	20.82	0.59	3326	99	70	66	62
30	28.98	25.98	21.23	18	3'-0"	33	55	1815	1⅛"	1010	825	33	21.48	0.61	3430	102	72	68	64

NOTE: Length of Bars in Parapets same as lengths of I-Beams.

PLATE 29.—(*Continued*)

	Table No. 2		STRAIGHT A = 30° B = 30°						*Table No. 3*		15° SKEW A = 30° B = 15°					
Height of Abutment	Lengths of Wings		Cubic Yards Third Class Concrete		Cubic Yards Third Class Masonry		Cubic Yds. each ft. in length of Culvert more or less than 25 ft.		Lengths of Wings		Cubic Yards Third Class Concrete		Cubic Yards Third Class Masonry		Cubic Yds. each ft. in length of Culvert more or less than 25 ft.	
H	L	M	2 Abut's	4 Wings	2 Abut's	4 Wings	Concrete	Masonry	L	M	2 Abut's	4 Wings	2 Abut's	4 Wings	Concrete	Masonry
6	3.87	3.87	23.3	5.5	28.5	6.5	0.94	1.17	3.51	3.67	24.2	5.2	29.7	6.1	0.98	1.21
7	5.60	5.60	28.3	9.2	34.3	10.9	1.17	1.41	5.06	5.40	29.6	8.8	36.0	10.4	1.20	1.47
8	7.33	7.33	34.0	13.8	40.5	16.4	1.38	1.68	6.62	7.13	35.4	12.9	42.7	15.5	1.44	1.74
9	9.06	9.06	40.0	19.4	47.3	22.7	1.63	1.95	8.16	8.86	41.6	18.3	49.6	21.6	1.69	2.03
10	10.79	10.79	46.4	25.4	54.5	30.2	1.88	2.25	9.72	10.59	48.2	24.3	57.2	28.8	1.95	2.33
11	12.52	12.52	53.3	33.4	62.3	39.1	2.16	2.56	11.27	12.32	55.2	31.7	65.1	37.1	2.24	2.66
12	14.26	14.26	60.8	42.1	70.5	49.1	2.44	2.89	12.82	14.06	62.5	39.9	73.5	46.6	2.54	3.00
13	15.99	15.99	72.2	55.5	84.7	64.3	3.01	3.49	14.38	15.79	76.8	53.0	88.4	61.3	3.12	3.62
14	17.72	17.72	81.5	68.4	94.2	78.5	3.37	3.89	15.53	17.52	86.0	64.5	98.6	74.4	3.50	4.04
15	19.45	19.45	91.0	82.4	104.2	94.0	3.75	4.31	17.48	19.25	95.7	78.4	109.3	89.6	3.89	4.47
16	21.18	21.18	101.0	98.2	114.5	111.4	4.15	4.74	19.11	20.98	106.0	93.7	120.5	106.3	4.31	4.92
17	22.92	22.92	111.1	115.9	125.3	130.7	4.56	5.19	20.58	22.72	116.1	110.1	131.8	124.5	4.74	5.39
18	24.65	24.65	121.8	134.4	136.3	152.6	5.00	5.67	22.14	24.45	127.1	128.8	143.7	145.0	5.19	5.88
19	26.38	26.38	132.7	156.2	147.7	175.7	5.45	6.16	23.69	26.18	138.3	149.0	155.8	167.3	5.66	6.38
20	28.11	28.11	144.0	179.5	159.5	201.4	5.93	6.67	25.24	27.91	150.2	170.8	168.4	191.6	6.15	6.91

PLATE 29.—(*Continued*)

Table No. 4			30° SKEW A = 30° B = 15°						*Table No. 5*		45° SKEW A = 45° B = 0°					
Height of Abutment	Lengths of Wings		Cubic Yards Third Class Concrete		Cubic Yards Third Class Masonry		Cubic Yds. each ft. in length of Culverts more or less than 25 ft.		Lengths of Wings		Cubic Yards Third Class Concrete		Cubic Yards Third Class Masonry		Cubic Yds. each ft. in length of Culvert more or less than 25 ft.	
H	L	M	2 Abut's	4 Wings	2 Abut's	4 Wings	Concrete	Masonry	L	M	2 Abut's	4 Wings	2 Abut's	4 Wings	Concrete	Masonry
6	3.4	4.44	27.0	5.6	33.3	6.8	1.09	1.35	3.6	4.24	33.0	5.5	40.5	6.8	1.34	1.65
7	4.9	6.56	32.8	8.8	40.2	11.3	1.33	1.63	5.1	6.36	40.5	9.7	49.5	11.2	1.63	2.00
8	6.4	8.69	39.5	14.4	47.6	17.0	1.59	1.94	6.6	8.49	48.3	14.5	58.8	17.1	1.95	2.37
9	7.9	10.81	46.3	20.2	55.7	23.8	1.87	2.26	8.1	10.81	57.0	20.3	68.5	23.8	2.29	2.76
10	9.4	12.93	53.7	26.9	64.0	31.7	2.17	2.60	9.6	12.73	66.0	27.2	78.5	31.8	2.66	3.18
11	10.9	15.05	61.6	34.7	72.9	40.9	2.48	2.95	11.1	14.85	75.4	35.0	89.2	41.0	3.04	3.63
12	12.4	17.17	70.0	43.7	82.3	51.4	2.82	3.34	12.6	16.97	85.5	44.1	100.5	51.4	3.46	4.09
13	13.9	19.30	85.7	58.3	99.2	67.5	3.48	4.03	14.1	19.10	105.0	58.8	121.5	67.9	4.26	4.94
14	15.4	21.42	96.0	71.4	110.7	82.8	3.89	4.49	15.6	21.22	117.6	71.8	135.3	83.0	4.76	5.50
15	16.9	23.54	107.0	86.4	122.4	99.5	4.33	4.97	17.1	23.54	130.8	87.1	149.8	99.4	5.31	6.09
16	18.4	25.66	118.0	102.9	134.6	117.3	4.79	5.48	19.6	25.46	144.7	103.6	165.0	117.4	5.87	6.71
17	19.9	27.78	129.7	121.2	147.0	137.2	5.27	6.00	20.1	27.58	159.0	121.6	180.6	137.8	6.46	7.35
18	21.4	29.90	142.0	141.1	160.5	159.7	5.77	6.54	21.6	29.70	173.0	141.8	197.0	159.7	7.08	8.02
19	22.9	32.02	154.6	163.5	174.0	184.4	6.30	7.11	23.1	31.82	189.6	164.1	213.9	184.7	7.72	8.71
20	24.4	34.14	168.0	188.5	188.0	211.2	6.84	7.70	24.6	33.94	206.0	189.1	232.0	211.6	8.39	9.43

PLATE 29.—(*Continued*).

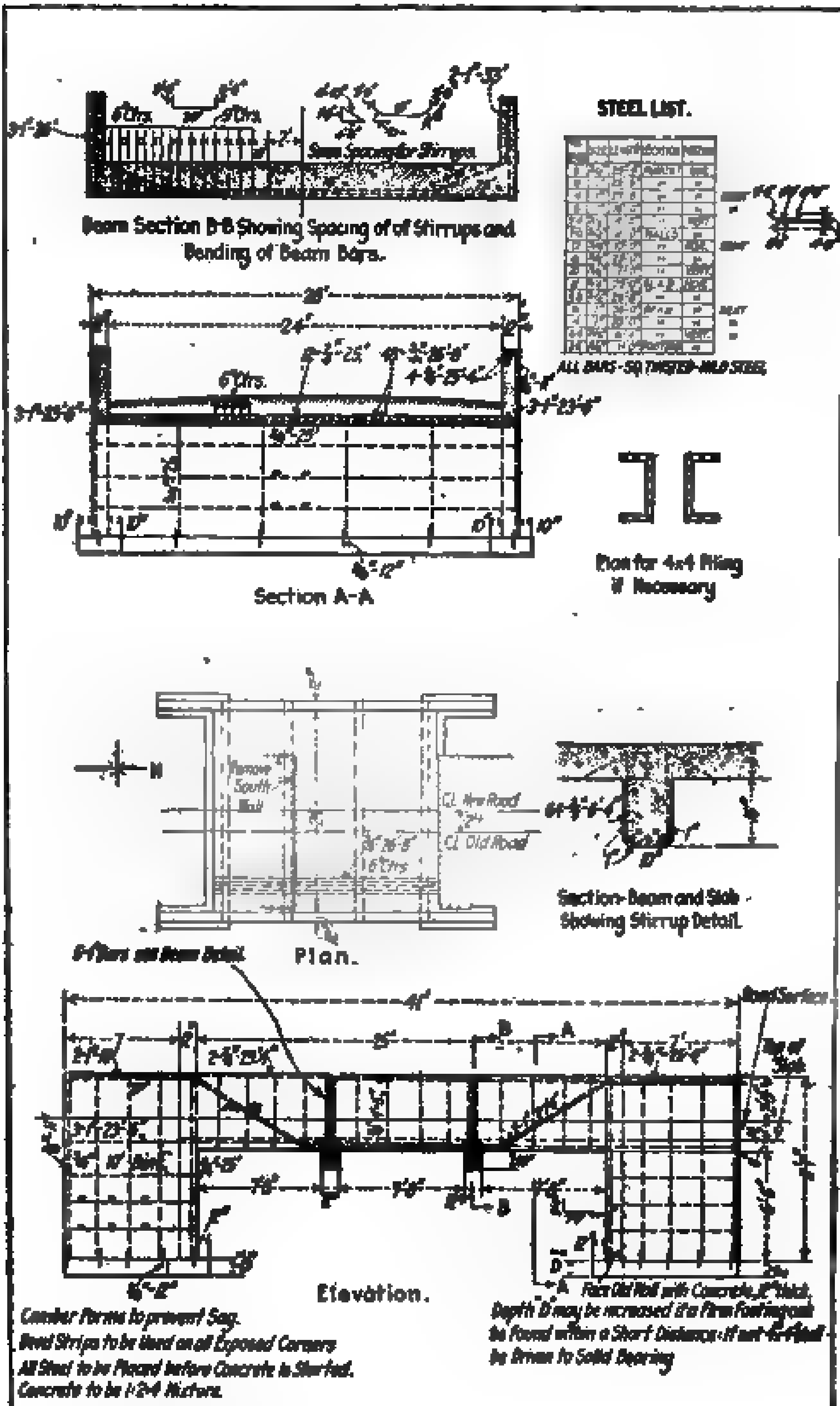
Table No. 6 Length of Culvert	Number I-Beams For Concrete Covers only Spacing 2'-6"	2'-9"	3'-0"	P = Length of Abutments 15° Skew	30° Skew	45° Skew
18	5	5	4	18.64	20.79	25.46
19	5	5	5	19.67	21.94	26.97
20	6	5	5	20.71	23.09	28.28
21	6	6	5	21.74	24.25	29.70
22	6	6	5	22.78	25.40	31.11
23	7	6	6	23.81	26.66	32.53
24	7	6	6	24.85	27.71	33.94
25	7	7	6	25.88	28.87	35.36
26	8	8	7	26.92	30.02	36.77
27	8	8	7	27.95	31.18	38.18
28	9	8	7	28.99	32.33	39.60
29	9	8	8	30.02	33.49	41.01
30	9	9	8	31.06	34.64	42.43
31	10	9	9	32.09	35.80	43.84
32	10	9	9	33.13	36.95	45.26
33	11	10	9	34.16	38.10	46.67

APPLICATION OF TABLES

Quantities for a 30° Skew Concrete Culvert, concrete top, length 30 feet, opening 13 feet high and 12 feet wide. From Table 1, an opening 12.12 ft. wide 30° Skew is a 14-ft. span requiring (see 30-ft. length, Table 6) 9 I-Beams spaced 2'-9" c. to c. (9 × 400) = 3600 lbs. I-Beams; 218 lbs. Bars; 400 + (5×16) = 480 sq. ft. Ex'p'd Metal; 9.78 + (5 × 30) = 11.28 cu. yds. 2d class Concrete 32 lin. ft. Pipe Rail. An opening 13 ft. high will require Abutments, 16 ft. high (13' + 2' in ground + 10" I-Beam = 15'-10"). From Table 4, Abutments = 118.0 cu. yds., Wings = 102.9 cu. yds. (5×4.79 = 23.95 cu. yds. 5 ft. extra length of Culvert) 118.0 + 102.9 + 23.95 = 244.85 cu. yds. 3d Class Concrete.

For Spans of more than 17 feet, use Masonry Tables for Concrete Abutments and Wings.

PLATE 30.—TYPICAL METHOD OF REINFORCING A CONCRETE PARAPET GIRDER BRIDGE.



Design used by Monroe County, New York State.

Underdrainage

The purpose of under drains on hard surfaced roads is to intercept the ground water before it reaches and softens the sub-grade. On a sidehill road the drain is usually placed under the ditch on the uphill side (see Figure No. 24, position No. 1) where the greatest

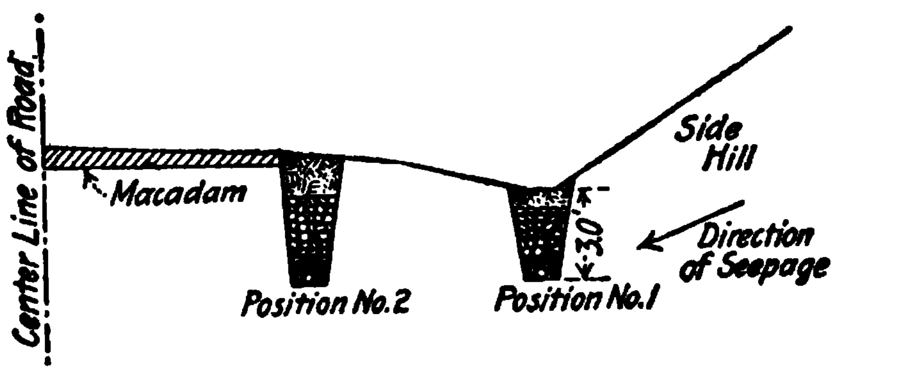


FIG. 24.

depth can be obtained with the least excavation and where the water is caught as it flows out of the hill.

Some engineers place the drain in position No. 2 (Figure 24) but this requires more excavation for the same depth and for side

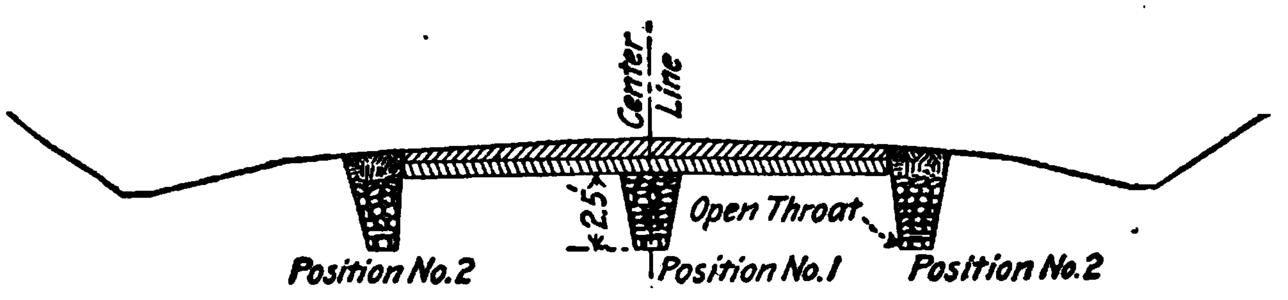


FIG. 25.

seepage is not as effective. The usual depth for drains is three feet below the surface.

Where the road is on a descending grade, the water will flow out of the hill directly under the stone and the drain is placed as in

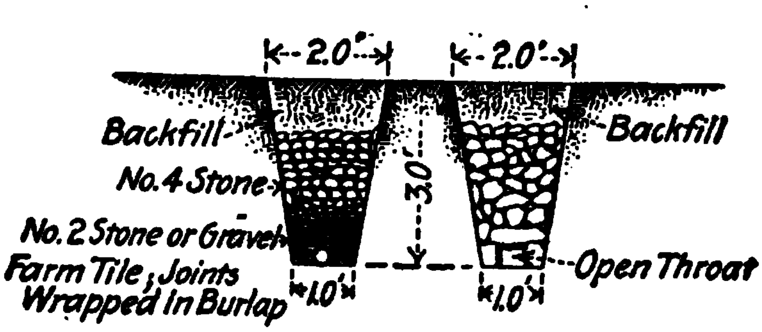


FIG. 26.

Figure 25, position 1, or two drains are built in position No. 2. Position 1 is the usual practice, being cheaper and more effective.

The argument for the two side drains is, that in case the throat becomes clogged, a side drain can be taken up without disturbing

the macadam. This rarely occurs in a center drain, as it is better protected than those in position 2 and in case the center drain does clog, side drains can be constructed at any time.

There are two kinds of drain in general use:

No. 1 is built entirely of stone with an open throat roughly laid as shown; it is satisfactory in a water-bearing strata of gravely

Fig. 27.

loam or clay, but does not work so well in quicksand, which is liable to fill it up. It is generally cheaper, however, than No. 2.

No. 2 is built of porous farm tile or vitrified tile of a suitable size (usually 3" to 6") with open joints, wrapped with a double or triple layer of burlap, the pipe is surrounded and covered with clean gravel or ¾" crushed stone to a depth of 6", the remaining depth of the trench being filled with large stone. If this drain has a good fall and the outlet is kept free, it will rarely clog even in bad quicksand.

The author has successfully used the following method to prevent the outlet from clogging; after being brought out from under the macadam, the drain is continued under and across the ditch line, then keeping outside the ditch line, and using a slightly smaller gradient than that of the open ditch, the tile is continued down the hill until it reaches a point eight or nine inches above the ditch grade. Here it is turned into the open ditch through a small concrete head-wall and what little material it tends to deposit is washed down the ditch by the surface water (see Figure 27).

Summary of Chapter.—The present bridge situation demands attention as even in the richer states it is lagging behind the improvement of the roads. The separation of Bridge and Highway funds and the lack of central control often results in the ridiculous situation of a modern road limited in use by antiquated bridges.

Road pavements can be strengthened from year to year by additions in thickness and the construction of better surfaces on top of existing improvements but structures must be rebuilt entire to increase their strength and for this reason more foresight in regard to future traffic must be exercised in their design. A liberal allowance for increased loads is desirable. Liberality in size of waterway for culverts is also good policy as it adds only slightly to the cost and materially decreases the difficulties of maintenance.

The design of drainage must be complete and reasonable and if the existing scheme is not feasible it should be changed regardless of law-suits as whenever an improvement is made it is always cheaper to correct mistakes at that time than it will be at a later date as every year's use fix the channels more firmly.

The selection of type offers the greatest chance for reasonable economy in culvert and bridge design.

CHAPTER IV

LOW TYPE EARTH, SAND-CLAY AND GRAVEL ROADS

These types of construction are the initial steps in final road improvement and serve to gradually pull traffic "out of the mud." They are the only types that can be reasonably built in unsettled communities or scattered agricultural districts without outside aid and if properly located, graded and drained are well worth very careful engineering attention. They constitute such a large percentage of the mileage of road work that they are probably of more economic importance than the higher type macadams and rigid pavements.

They however are only makeshifts under adverse weather conditions (5 months in the year) as compared with the more substantial forms and must be regarded as such. They require continuous maintenance but not the same degree of perfection in maintenance as better roads nor anything like as much money in yearly upkeep as traffic is light and no one expects or demands that roads of this kind be kept in perfect condition.

The gravel road will serve in a fairly satisfactory way up to about 250 moderately light rigs per day.

The following table taken from Agg's Construction of Roads and Pavements gives an idea of the traffic capacity of gravel and macadam roads.

This shows approximately the practical limit of these roads and indicates that earth, sand clay, or gravel are reasonable for a large mileage.

Average Daily Traffic Limits in Massachusetts

Table showing results of observations of traffic on different types of road surfaces in Massachusetts. Standard road, 15 ft. in width; gravel or waterbound macadam, 5 or 6 in. in thickness, with adequate drainage and proper foundation, with 3 ft. gravel shoulder on each side.

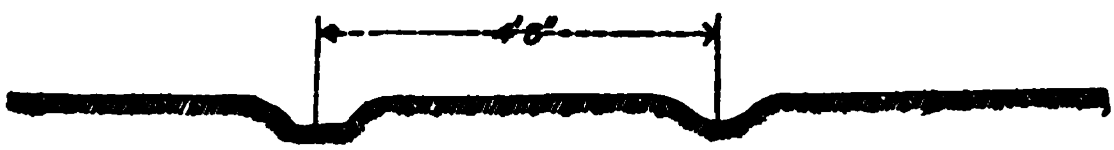
Type of Surface	Light Teams, Carriages, Wagons	Heavy Teams, One-horse	Heavy Teams, two or more Horses	Automobiles
A good gravel road will wear reasonably well and be economical with..........	50–75	25–30	10–15	50 to 75
Needs to be oiled with.....	50–75	25–30	10–15	Over 75
Oiled gravel, fairly good, heavy cold oil, ½ gal. to the sq. yd. applied annually with......................	75–100	30–50	20	500 to 700 or more
Waterbound macadam will stand with...............	175–200	175–200	60–80	Not over 50 at high speed
Cold oil or tar will prove serviceable on such macadam with.................	175–200	175–200	60–80	50–500
Macadam will then stand, but the stone wears, of course, with.............	175–200	175–200	60–80	500 or more
*Waterbound macadam with hot asphaltic oil blanket will be economical with....	100–150	50–75	25–30	1500 and more with fewer teams
And stand at least.........	....	....	....	50 trucks
But will crumble and perhaps fail with over........ (On narrow tires, ice, farm and wood teams, etc.)	150	75	30	
*Waterbound macadam with a good surface coating of tar (½ gal. to the sq. yd.) will stand with........... (But requires to be recoated annually with ¼ gal. of tar per sq. yd.)	100–150	50–75	25–30	1500 or more

It is assumed that all road surfaces are kept constantly patched, that before applying bitumen the road surface is cleaned and patched, and the bitumen covered with pea stone and sand or gravel and kept covered so that it never picks up.

* Author's Note.—One coat penetration bituminous macadam will stand any number of light autos and more steel tire or truck traffic than shown above, because it takes the wear more directly and has no blanket coat which crumbles under such traffic.

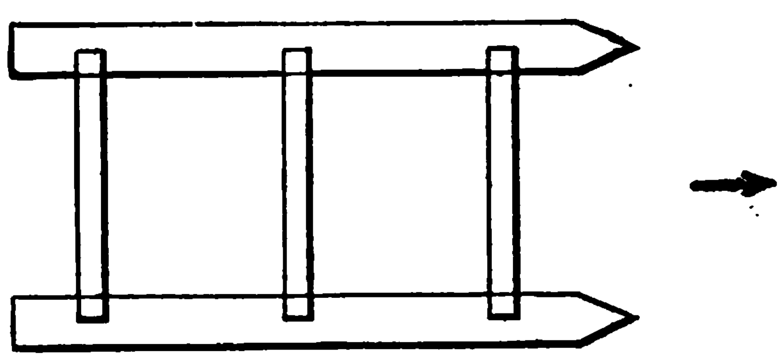
EARTH ROADS

Rut Roads.—The simplest form of road is the so-called rut road used in the arid regions of New Mexico and the southwest. They are constructed by clearing the right-of-way of brush and then cutting two shallow parallel ruts in the surface vegetation or soil crust by means of two cutting irons gaged to fit the ordinary wagon track. A wagon trail of this kind can be constructed for from $5.00 to $15.00 per mile; can be used by autos with fair comfort at speeds up to 15 miles an hour and on the flat mesas of this



Rut road.

district are more lasting and satisfactory than the ordinary turnpiked section as so little rain falls that an elevated fill grade does not consolidate and is worse than useless for traffic. On these rut roads any rain storms that occur wash the coarser particles of the soil into the ruts and gradually an armored track is formed below the general elevation of the mesa. No drainage structures are necessary where construction of this kind is adopted.



Cutting rig for rut road.

Earth Roads.—The same principles of grade, section and drainage apply to this class of road as to the higher types except that the surface ditches are generally made slightly deeper and more care is taken with the underdrainage; this is necessary as the earth road becomes more easily saturated with water than types which are sealed over on the surface. If the natural soil is good road material such as gravel, disintegrated rock, hardpan or sandy loam this type of construction carefully graded, drained and shaped by blader finish and maintained by dragging makes a satisfactory road for light traffic. Their cost depends on the amount of grading required and the methods that can be used. The cost of drainage culverts, incidentals, etc., will vary but will run about $600 per mile for good work.

Simple blade machine turnpiking, where the dirt from the ditches

makes the center fill cost (in districts similar to Wyoming in 1914-1915) about $150 per mile. The same work at present (1918) is bid off for about $200 per mile. A fair relative price for first-class work of this kind including drainage and incidentals can be placed at $600 to $800 per mile.

In rolling country requiring grade reductions by cut and fill and wagon haul a fair relative price including drainage and incidentals is approximately $1500 to $3000, where no rock is encountered.

In mountain road work where the excavation runs anywhere from 1000 cu. yd. to 30,000 cu. yd. per mile with a large percentage of rock the cost will run anywhere from $1000 per mile to $25,000 per mile. A fair average for such conditions is $3000 to $6000 per mile.

As previously stated it is entirely a matter of required grading. The approximate cost of different classes of grading are taken up in more detail in Chapter X on "Preliminary Investigations."

Current practice in earth road sections is shown in the following plates.

Mountain Roads,	Plate No 11, page	68
Wyoming Standards	" " 5, "	55
Iowa Standards	" " 31, "	132
Pennsylvania Standards,	" " 32, "	132

Current practice in grading and finishing are given in typical specifications, page 139.

Earth road maintenance is discussed in Chapter VII.

Where the soil is not a good road material the surface is improved by artificial mixtures of selected soil or by surfacing with gravel, chert, disintegrated granite, slag, shell cinders, etc., in fact any local material that gives body to the surface and prevents softening.

Sand-Clay Treatments

Where the natural soil is clay the resisting power of the surface during wet weather can be increased by the addition of sand. Where the natural soil is deep sand the surface can be made firm and resilient by the addition of clay. The so-called sand-clay treatment aims to provide a surface layer of mixed sand and clay about 10" to 12" deep (see Plate No 33, Alabama Standards) in which the sand forms the body and the clay just fills the voids in the sand and acts as a binder. It can be readily seem that different materials will require different proportioning of the sand and clay; the only sure way to get the best results is by experiment on the road during construction but to give an idea of the approximate proportioning the following list of recommended mixes is taken from the Good Roads Year Book of the American Highway Association, 1917.

Sand-Clay Roads

The grains of which sand is composed are usually hard and tough and able to resist abrasion if held securely in place. In an asphalt pavement they are held by the asphalt and a wearing surface of great resistance to

PLATE 31.—IOWA TYPICAL SECTION EARTH ROADS.

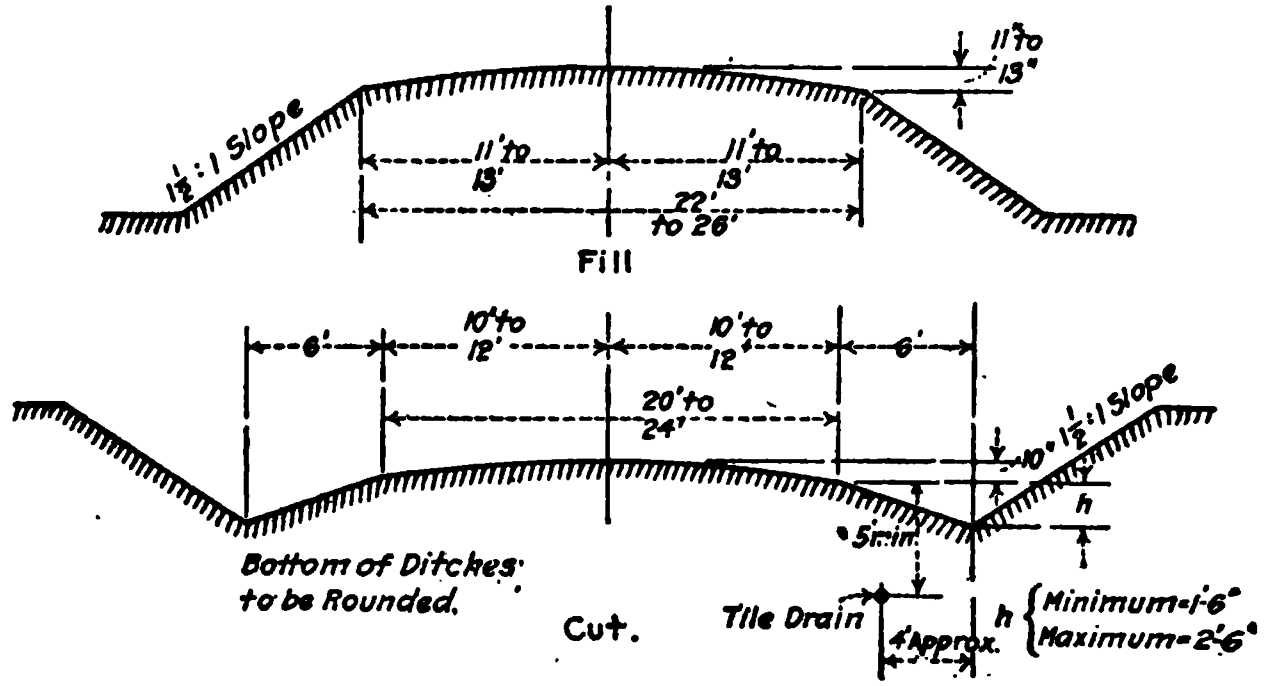
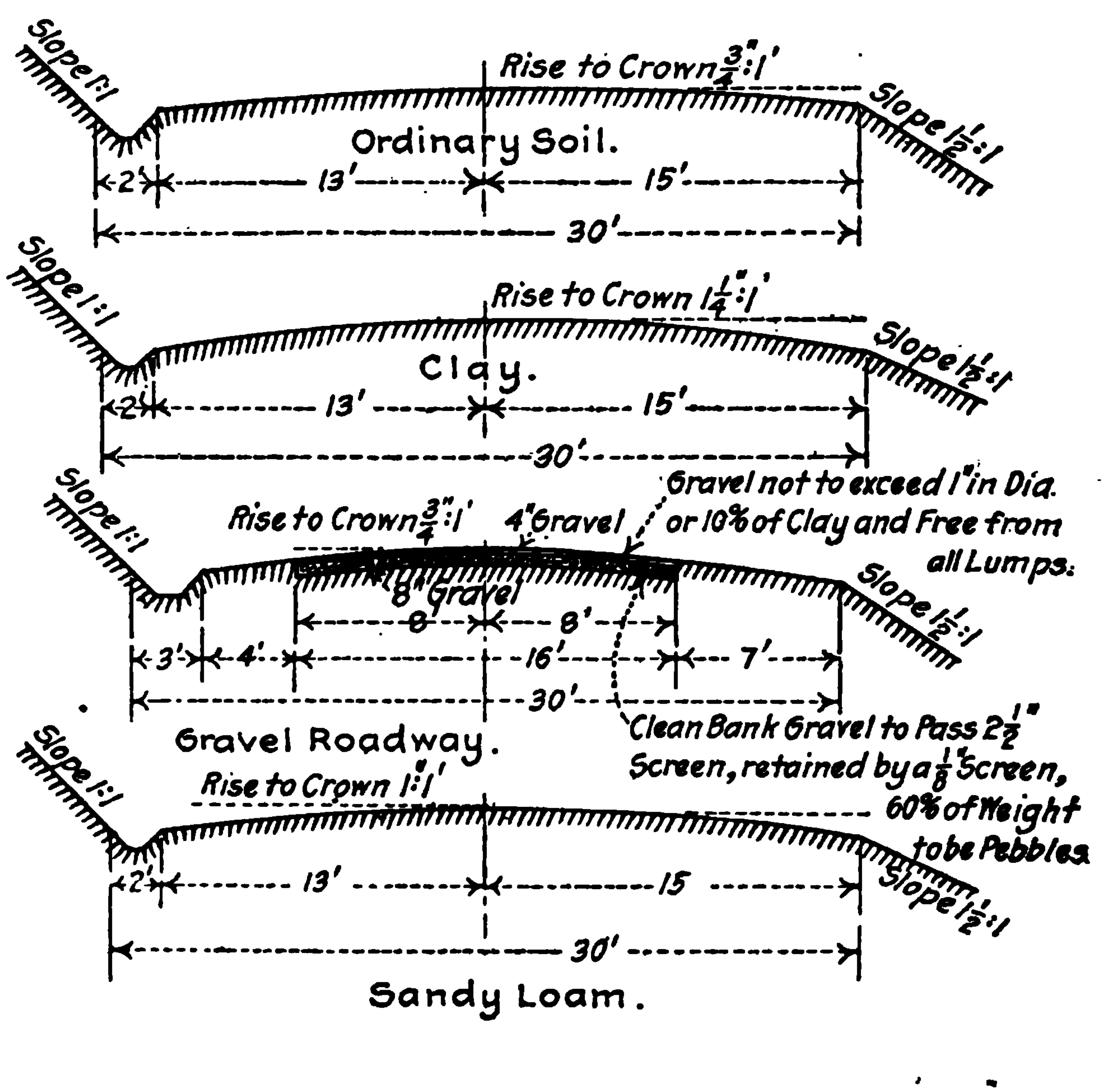


PLATE 32.—PENNSYLVANIA STANDARD EARTH AND GRAVEL ROADS.



abrasion results. In a sand-clay road they are bound together by clay in a less firm manner but one giving excellent results on well drained roads carrying light traffic. The aim of the builder of such a road is to employ just enough of the stickiest clay at his command to fill the pores of the sand and to mix these materials together so thoroughly that there are neither lumps of clay nor pockets of loose sand left in the surfacing. This gives the maximum amount of hard sand to carry the traffic and the minimum amount of clay to bind it. More sand makes a less durable road and more clay makes one which becomes soft more rapidly when wet.

There is a great difference in the value of different clays for such work. Some of them become dough-like when mixed with a certain amount of water and can be molded into objects which retain their shape after drying. If these molded objects are immersed in water they will retain their form for a long time. These varieties are called "plastic clays" and the most plastic are called "ball clays." There are other varieties which fall to pieces more or less quickly when wet, as quicklime does, and they are therefore called "slaking clays." They are more easily mixed with sand than the plastic clays but they have much less binding power and a road built with them is less durable when dry and more easily rutted when wet. The amount of clay to be used can be determined by a simple field test described as follows by Andrew P. Anderson:

From typical samples of each of the available clays, test mixtures, varying by one-half part, are made with the sand so that each clay is represented by a set of mixtures ranging by successive steps from one part sand and three parts clay to four parts sand and one part clay. These are worked up with water into a putty-like mass and from each mix two equals quantities are taken and rolled between the palms of the hands into reasonably true spheres, labeled and placed in the sun to dry. When thoroughly baked, a set of spheres representing any one clay is placed in a flat pan or dish and enough water poured gently into the pan to cover them, care being taken not to pour the water directly on the samples. Some samples will begin to disintegrate immediately. Those breaking down most slowly contain most nearly the proper proportion of sand and clay for the particular materials. The relative binding power of the various clays may then be determined by comparing the hardness and resistance to abrasion of the various dry samples having the correct proportion of sand and clay, as determined by the water tests.

In February, 1917, representatives of 21 state highway departments and of the U. S. Office of Public Roads recommended the following mixtures for hard, medium and soft classes of sand-clay roads.

Hard Class.—Clay, 9 to 15%; silt, 5 to 15%; total sand, 65 to 80%; sand retained on a 60-mesh sieve, 45 to 60%.

Medium Class.—Clay, 15 to 25%; silt, 10 to 20%; total sand, 60 to 70%; sand retained on a 60-mesh sieve, 30 to 45%.

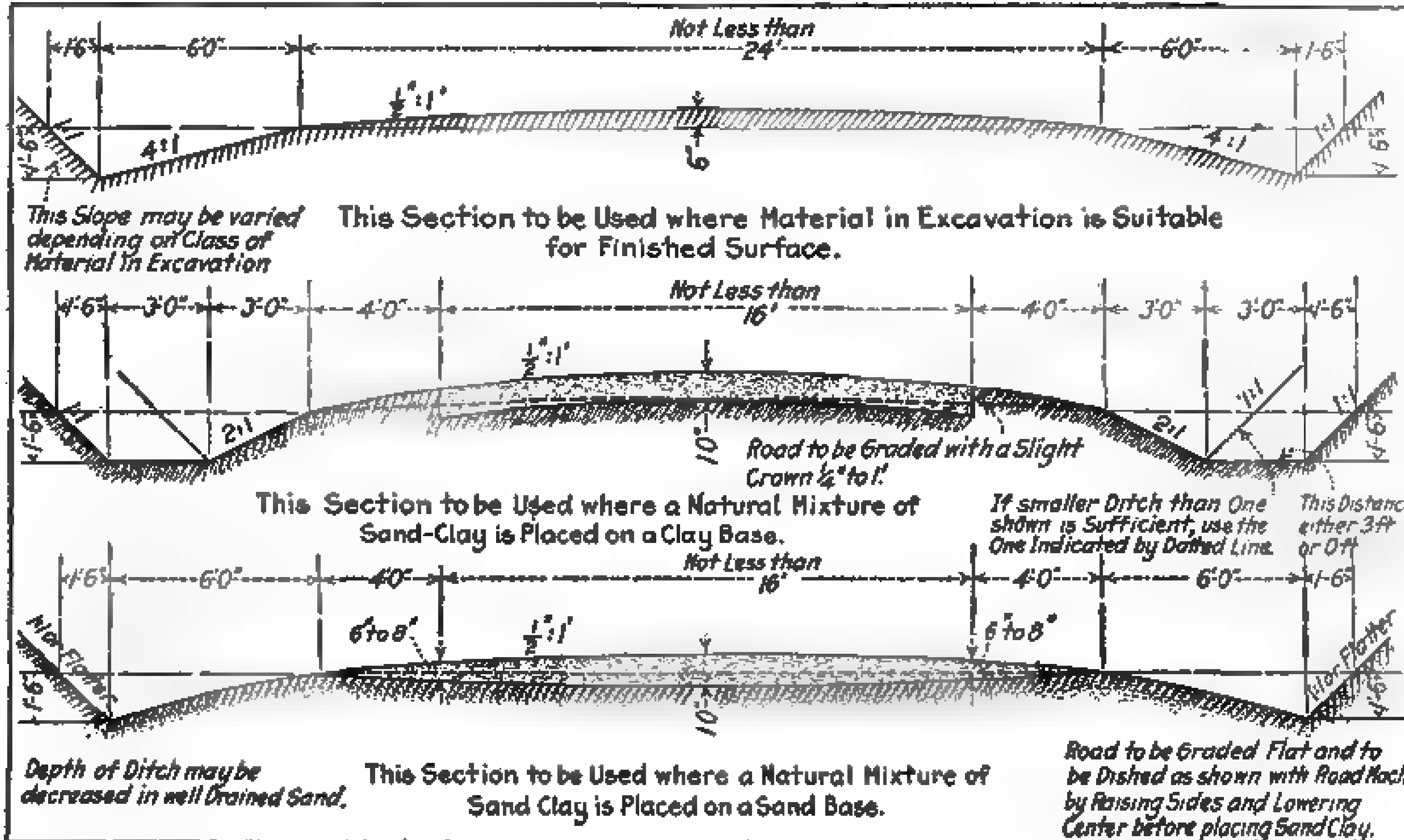
Soft Class.—Clay, 10 to 25%; silt, 10 to 20%; total sand, 55 to 80%; sand retained on a 60-mesh sieve, 15 to 30%.

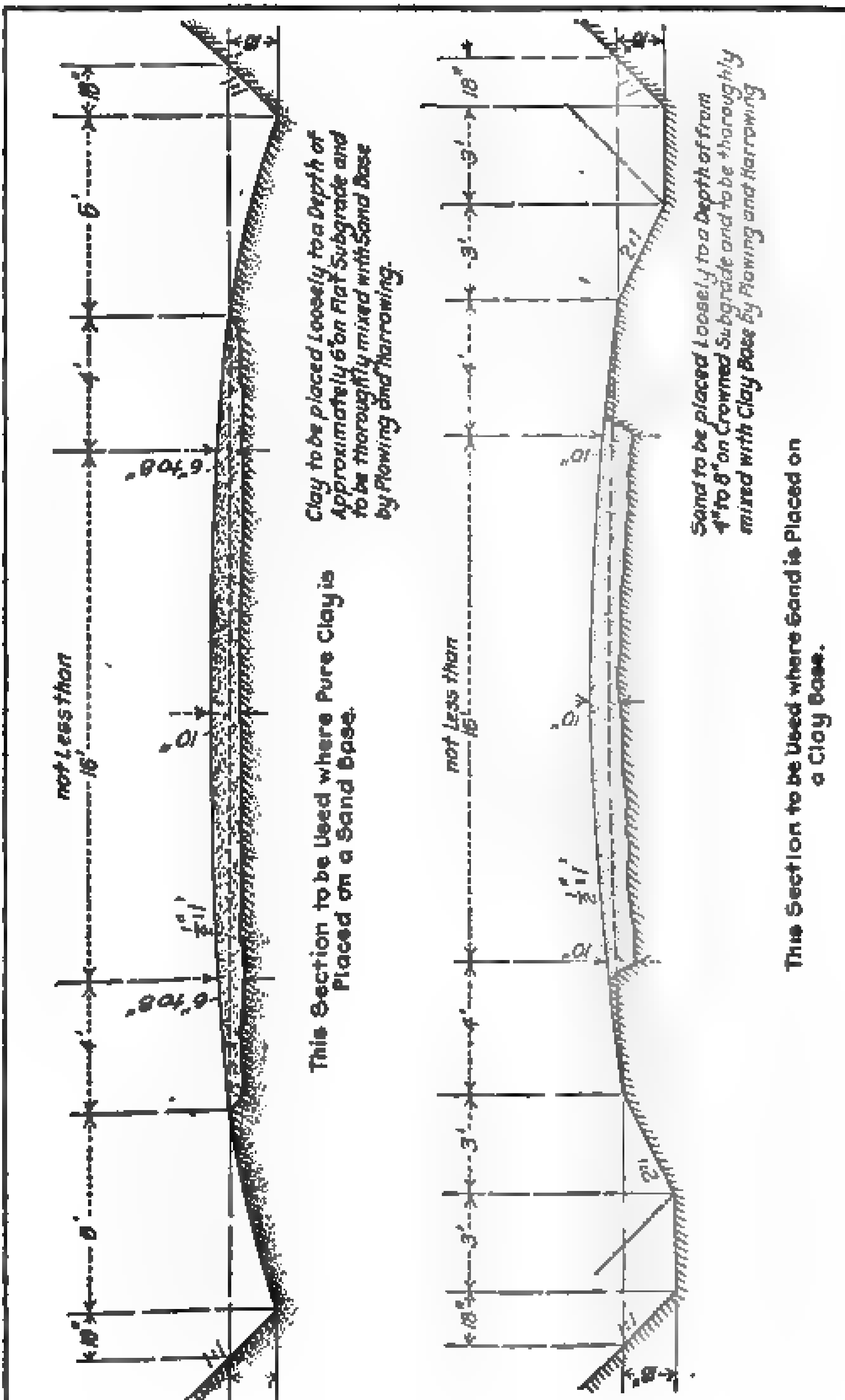
By clay is meant material separated by subsidence through water and possessing plastic or adhesive properties; it is generally below 0.01 mm. in diameter. By silt is meant the fine material other than clay which passes a 200-mesh sieve and is generally from 0.07 to 0.01 mm. in diameter. By sand is meant the hard material which passes a 10-mesh sieve and is retained on a 200-mesh sieve, and is generally from 1.85 to 0.07 mm. in diameter.

The larger part of the following explanation of the construction of sand-clay roads was prepared by W. S. Keller, State engineer of Alabama, where many miles of sand-clay roads have been built and are giving good satisfaction.

Every farmer who lives in a section of country where both sand and clay are prevalent, is more than likely traveling over a section of natural sand-clay road but is ignorant of the fact. He can call to mind some particular spot on the road he travels though it may not be more than 100 feet in length, that is always good and rarely requires the attention of the road hands. Good drainage will be noticed at this place and if he takes the trouble to investigate, he will find that a good mixture of sand and clay forms the wearing surface. If this 100 feet of road is always good then the entire road can be made like it provided man will take advantage of the lesson

PLATE 33.—STATE OF ALABAMA. TYPICAL SAND CLAY ROAD SECTION.




not Less than 16'
Clay to be placed Loosely to a Depth of Approximately 6" on Flat Subgrade and to be thoroughly mixed with Sand Base by Plowing and Harrowing.
This Section to be Used where Pure Clay is Placed on a Sand Base.
not Less than 16'
Sand to be placed Loosely to a Depth of from 4" to 8" on Crowned Subgrade and to be thoroughly mixed with Clay Base by Plowing and Harrowing.
This Section to be Used where Sand is Placed on a Clay Base.

taught by nature and grade the road so that the drainage will be good and surface the balance of the road with the same material. If it is not possible to find this ready mixed surfacing material convenient to the road it may be possible to find the two ingredients in close proximity. In case the road after grading shows an excess of sand, clay should be added, or in case clay predominates, sand should be added to produce good results. There are four general ways in which sand-clay roads may be built.

1. Ready mixed sand and clay placed on clay, sand or ordinary foundation.
2. Sand and clay placed on soil foundation and mixed.
3. Clay hauled on a sand foundation and mixed with the sand.
4. Sand hauled on a clay foundation and mixed with the clay.

Taking up the various methods in order.

1. A natural mixture of sand and clay can often be found where the two materials are found separate. The most important point is to know the natural mixture when seen. The very best guide to this is to find a natural piece of good road. A sample from the best of this good section will, by comparison, indicate what is required, close to the road to be surfaced. This natural mixture of sand and clay can be noticed where red clay and sand crop out, usually well up in the hills, having ditches and cuts the appearance of red sandstone. A good stratum of well mixed sand and clay will stand perpendicular in cuts and ditches, resisting erosion almost as well as sandstone. A test of the best natural sand-clay mixtures will show the sand forms about 70% of the whole. The test is very simple. Take an ordinary medicine glass, measures 2 ounces of the mixture into the glass and wash out the clay. Dry the remaining sand and measure again on the medicine glass. The loss will be the amount of clay originally contained in the mass.

Before placing any sand-clay on the road, the road should be graded to the desired width. The surface of the graded road should be flat or slightly convex. The sand-clay should be put on from 8 to 12 inches in thickness, depending on the character of the sub-grade or foundation. With a hard clay for foundation, 8 inches of sand-clay will suffice. If the sub-grade is sand it is well to put on as much as 12 inches of the surfacing material. After a few hundred feet of surfacing material has been placed, a grading machine should be run over it to smooth and crown the road surface before the top becomes hard and resists the cutting of the blade. It is a good plan to turn the blade of the machine so as to trim the edges of the surface part, discharging the excess sand and clay onto the earth shoulders. After one round trip with the blade turned out, the remaining dress work with the machine should be with the blade turned in, with the exception of one trip down the center of road with the blade at right angles to the axis of the road for the purpose of distributing any excess of material left in the center.

After the machine work, it is well to follow with a drag, which smooths any rough places left by the machine and leaves the road with a smooth, even surface. A sand-clay road, unlike other roads, can not be finished in a short space of time. It can be left in an apparently finished condition with a hard smooth surface, but it will be found on close examination that the hard surface is in reality only a crust, below which there are several inches of loose material. After the first hard rain the crust softens, the road becomes bad and the work appears to be a failure. This, however, is just what is needed to make it eventually good. After the surface has dried until the mass is in a plastic state, it should be dragged until the surface is once more smooth, with proper crown, and should be kept this way by dragging at least once a day until the sun has baked it hard and firm. The mistake of keeping traffic off during this process of resetting should not be made. The continuous tamping of the wheels of wagons and hoofs of horses is just what is needed to compact the sand-clay into a homogeneous mass. The ordinary roller is not very effective in this work, but corrugated rollers have given excellent results. One type which is widely used has 18 cast iron wheels weighing 300 pounds each, which compress the bottom of the mixture first. As the material becomes more and more compact the wheels ride higher and higher and finally the surface is so hard that the roller does not sink into it at all. A drag is an indispensable machine in the construction of any kind of sand-clay road.

2. Sand and clay placed on a soil foundation and mixed. This is necessary where the old road has neither a sand nor clay foundation and it is impossible to find the two ingredients ready mixed, but possible to get both in separate state near at hand. The clay should first be placed on the road to a depth of 4 inches and the required width. It is not wise to place more

than a few hundred lineal feet of clay before the sand is hauled, as the clay rapidly hardens and makes the mixing process difficult. After, say, 400 feet of clay have been placed, the clay should be broken by means of a plow and harrow, if it has become hard, and sand to a depth of 6 inches placed on it. This should be plowed and harrowed in thoroughly. This is best done immediately following a rain, as the two can be more satisfactorily mixed. The traffic aids the mixing and should be encouraged on the road. After the mass appears to be well mixed, the road should be properly shaped, as previously explained. The road should be given watchful attention and should sand or mud holes appear, a second plowing and mixing should be given it.

3. Clay hauled on a sand foundation and mixed with the sand. The mixing process is similar to that described under second head. It is only necessary to add that as the foundation is sand, a little more clay will be necessary than where the foundation is of clay or soil.

4. Sand hauled on a clay foundation and mixed with clay. The clay foundation should be plowed to a depth of 4 inches and harrowed with a disk or tooth harrow until the lumps are thoroughly broken or pulverized. Sand should then be added to a depth of 6 inches and mixed as before described.

Sand and clay can be mixed best when wet, but as most road construction is done in the summer months, it is necessary to do most of the mixing dry and keep the road in shape after the first two or three rains, while the passing wagons and vehicles give the road a final wet mixing. A sand-clay road is the cheapest road to maintain, for the reason that it can be repaired with its own material. With a drag or grading machine ruts can be filled with material scraped from the edges, whereas on gravel or macadam roads, this is not possible. The repairing of these roads can be done almost exclusively with the drag, only enough hand work being required to keep the gutters open and the growth of weeds cut on the shoulders. Holes are repaired by adding more sand-clay, and when many of them appear fresh sand-clay should be spread over the surface of the road. If the road gets into really bad condition, the roadbed should be plowed up, reshaped and fresh sand-clay added. This is unnecessary where the road is maintained properly and the travel is not too heavy for the type of construction.

The maintenance of sand-clay is discussed in Chapter VII. Specifications for sand-clay are covered in Part III.

Sand-clay roads can not be considered as finished until traffic has used them for a year or two and all the small areas showing improper mix have been remedied by maintenance.

The cost of surfacing with sand-clay varies as any form of construction with labor, length of haul, cost of materials, etc., but generally adds from 15c. to 35c. per square yard to the cost of an earth road. A fair comparative figure would add $1000 to $2000 per mile for a 16′ width of sand-clay to the cost of an ordinary dirt road in the same location.

Sand-clay construction is not advised if good road gravel or other coarse local materials are available.

GRAVEL ROADS

A coarse well graded gravel is the most satisfactory material for a cheap road. It gives body to the traveled track, binds well, rides easily and with a consolidated depth of 8″ to 20″ holds all ordinary loads after it is well consolidated. For wheel pressures and depths of metaling see Chapter V, page 152.

At the present time 50% of the mileage of surfaced roads in the U. S. are gravel roads.

They are however hard to consolidate quickly and need carefully continuous attention to prevent the formation of ruts, holes, or

humps. Gravel roads can not be built by merely dumping loose gravel on the road and then hoping that traffic will put it in shape. A large mileage has been built on this principle and the results are shameful. A successful gravel road requires *careful* select ion of the gravel, *careful* spreading, *careful* consolidation and *constant* maintenance. The best practice is shown in typical specifications Part III but the essential features will be summarized at this point.

Size of Gravel

Gravels suitable for road work are widely distributed over the country. They occur in bank deposits and in stream beds. The prime requisite of a gravel for foundation courses is that it contains a large percentage of coarse pebbles to give body and distribute the wheel loads. The prime requisite for a surfacing gravel is hardness of the stone and well graded coarse and fine particles which will take the wear evenly and bond well. Pit run gravel varies greatly as to size and composition even in a single pit and for this reason no definite limits can be well set for the proportion of sizing. In general it can be said that for foundation courses any coarse gravel, which when screened through a ¼" mesh contains less material passing the screen than retained on it, can be successfully manipulated without screening to remove the excess sand. In some localities this limit is not feasible on account of excessive fine material and the limit of fine material passing a ⅛" mesh is placed at 60% but in reality a gravel of this fineness does not produce satisfactory results and a road on which it is used becomes more nearly a sand-clay construction than a gravel type. For a top course the large stone above 1½" in size should be screened out and if pit run is used the sand passing the ¼" mesh should not exceed 40% of the volume. The most satisfactory top is a screened gravel but this adds materially to the cost. Where screened gravel is used ½" to 3" is satisfactory size for the bottom course and ½" to 1¾" for the top course.

The following specification has been recommended by the committee on Materials of the American Society of Civil Engineers.

Two mixtures of gravel, sand and clay shall be used, hereinafter designated in these specifications as No. 1 product (for top course) and No. 2 product (for middle and bottom courses).

No. 1 product shall consist of a mixture of gravel, sand and clay, with the proportions of the various sizes as follows: All to pass a 1½" screen and to have at least 60 and not more than 75% retained on a ¼ inch screen; at least 25 and not more than 75% of the total coarse aggregate (material over ¼ inch in size) to be retained on a ¾ inch screen; at least 65 and not more than 85% of the total fine aggregate (material under ¼ inch in size) to be retained on a 200-mesh sieve.

No. 2 product shall consist of a mixture of gravel, sand and clay, with the proportions of the various sizes as follows: All to pass a 2½ inch screen and to have at least 60 and not more than 75% of the total coarse aggregate to be retained on a 1 inch screen, at least 65 and not more than 85% of the total fine aggregate to be retained on a 200-mesh sieve.

Bonding Properties.—Clean gravel will not bond well. A small percentage of clay, loam or lime dust is desirable and necessary. This

per cent. ranges from 10% to 20%. For bottom course, pit run a gravel which contains over 20% of clay or loam should not be used; from 10% to 15% gives the best results. For top course 10% is about the maximum clay or loam allowable. Many so-called cementitious gravels of lime rock contain or produce under traffic a first-class rock dust binder of the highest grade. Clay or loam can be added to a clean gravel by mixing at the pit or by placing a thin layer of such material over the gravel as spread on the road and mixing it with the course during consolidation.

Spreading.—Gravel must be uniformly spread; there are two general methods; the trench spread (Plate No. 34) and the feather edge spread (Plates 35 and 36). The feather edge spread is probably the better method. In either case the depth should be uniform and the surface properly crowned. Gravel should not be dumped in piles; it should be spread along in windrows and the spreading finished by shoveling, raking or by road machine blade scrapers. If pit run gravel is used the course should be harrowed to distribute the sizes uniformly. The ratio of compacted to loose depth is approximately 1.2 or 1.25. That is a loose depth of 8" will compact to about 6½". If screened gravel is used the filler should be added before the course is rolled.

Consolidation.—Consolidation is the hardest feature of pit run gravel construction. Detail methods are described under gravel foundations, Chapter V, page 156. A combination of traffic and roller consolidation while the gravel is moist gives the best and quickest consolidation although traffic alone will put it down firmly if given time and the shape is kept intact by constant dragging with a hone or road machine. The following Minnesota Specification shows the methods employed where a road roller is not used.

MINNESOTA SPECIFICATIONS

Graveling

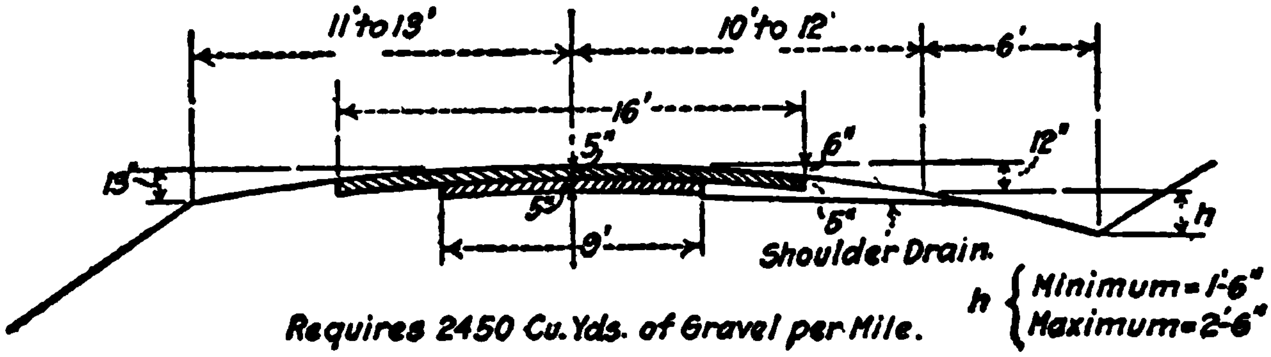
Description.—Graveling shall be construed to mean all surfacing with pit run gravel, screened gravel or crushed rock, or crushed rock screenings built in two or more successive courses.

Material.—All materials shall be of a quality approved by the engineer and shall be the best obtainable from the specified pit or quarry. Materials for the first course shall contain no stone which would be retained on a screen having 2½ inch openings. Materials for the second course shall contain no stone which would be retained on a screen having 1 inch openings. If available material contains an excess of sand, such excess shall be handled as provided by special specification for each job or project.

Sub-grade.—The cross-section of the sub-grade shall be as shown on the standard cross-section accompanying the plans. Graveling upon a wet muddy roadbed will not be permitted. If the graveling is not done in connection with the grading as a part of the same contract, the sub-grade for the full length of job embraced in the graveling contract, shall, before being graveled, be dressed by the County to the cross-section above mentioned. Thereafter, the contractor shall keep it dressed to the specified cross-section and free from ruts, waves and undulations, as part of the graveling contract. If the grading and graveling are performed under the same contract, the preparation of the sub-grade shall be performed as part of the grading item and no additional charge will be allowed therefor under the graveling.

Loading and Hauling.—Loading from pits shall be performed in such a manner and by such methods that a uniform grade of materials will be delivered upon the road. Stone exceeding the sizes specified, shall not be

PLATE 34.—IOWA TYPICAL GRAVEL ROADS.

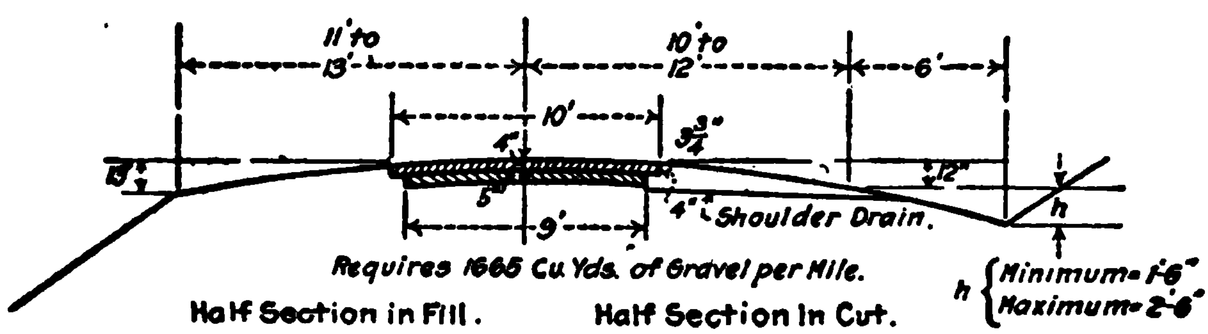


Requires 2450 Cu. Yds. of Gravel per Mile.

Half Section in Fill. Half Section in Cut.

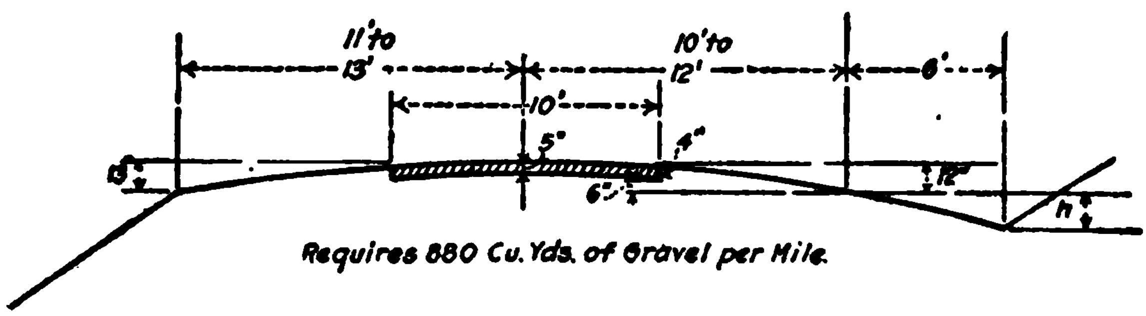
CLASS "A" DOUBLE TRACK GRAVEL ROAD.

CLASS "A" SINGLE TRACK GRAVEL ROAD.



Requires 1665 Cu. Yds. of Gravel per Mile.

Half Section in Fill. Half Section in Cut.



Requires 880 Cu. Yds. of Gravel per Mile.

Half Section in Fill Half Section in Cut.

CLASS "B" 10 FT. GRAVEL ROAD.

NOTE { The Patrol System for Maintenance is recommended for all Gravel Roads. The Class "B" Section is approved only with the understanding that a suitable Patrol System for Maintenance will be adopted. Wider Cross-sections using the same Thickness of Gravel will be approved on application.

PLATE 35.—NEW HAMPSHIRE GRAVEL ROAD SECTION.

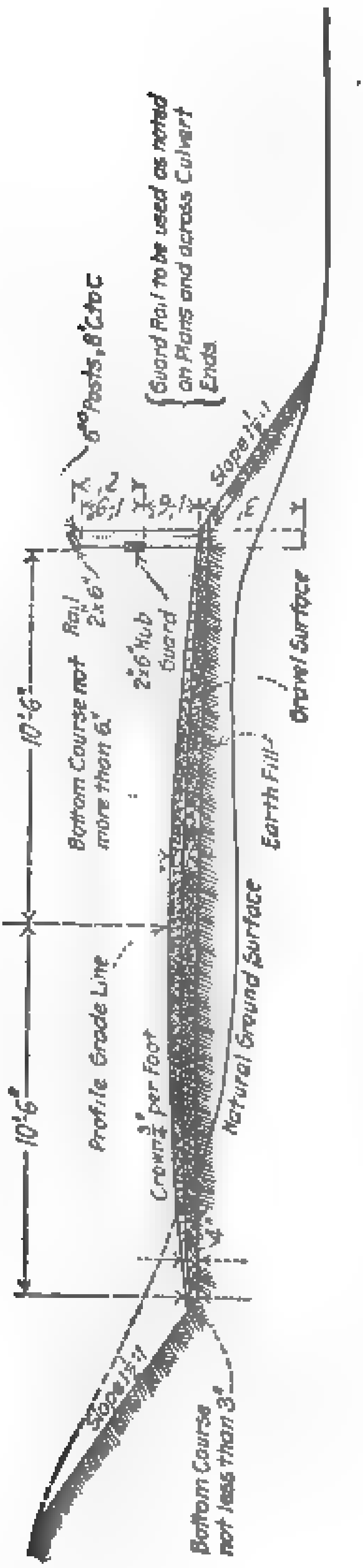
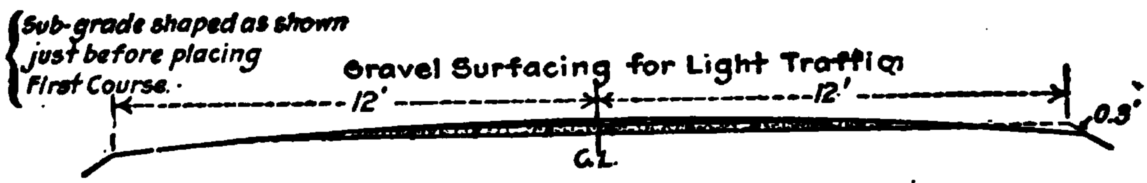
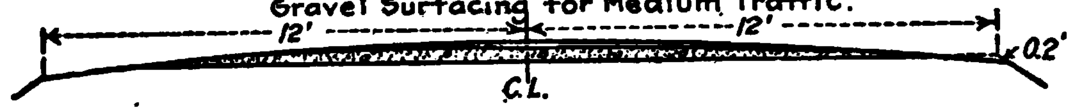


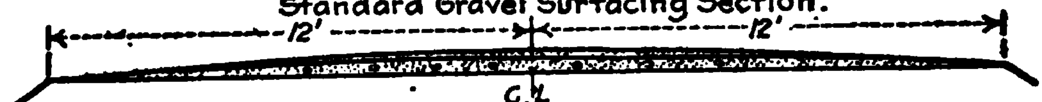
Plate 36.—Minnesota Gravel Road Section.



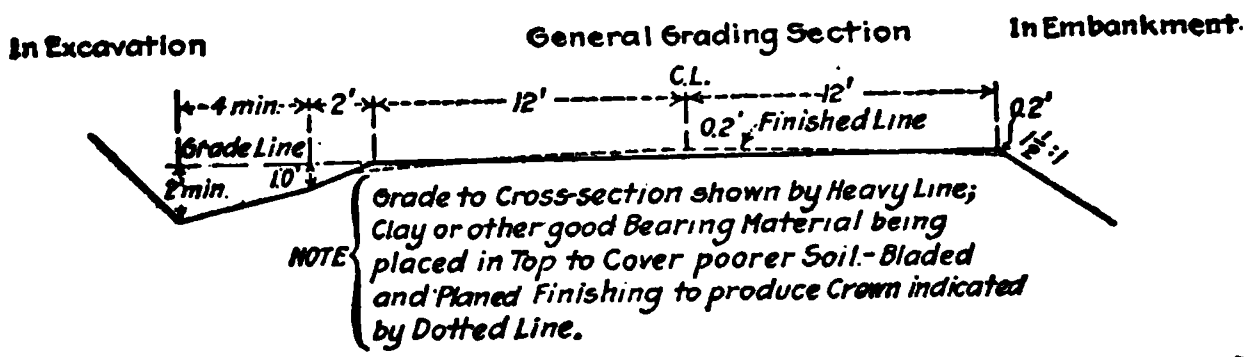
Depth 1st Course	0.00'	0.00'	0.18'	0.21'	0.23'	0.25'	0.23'	0.21'	0.18'	0.00'	0.00'	550 Cu.Yd. per Mi.
Depth 2nd Course	0.00'	0.00'	0.00'	0.10'	0.15'	0.15'	0.15'	0.10	0.00'	0.00'	0.00'	250 " " " "
Total Depth	0.00'	0.00'	0.18'	0.31'	0.38'	0.40'	0.38	0.31'	0.18'	0.00	0.00'	800 " " " "

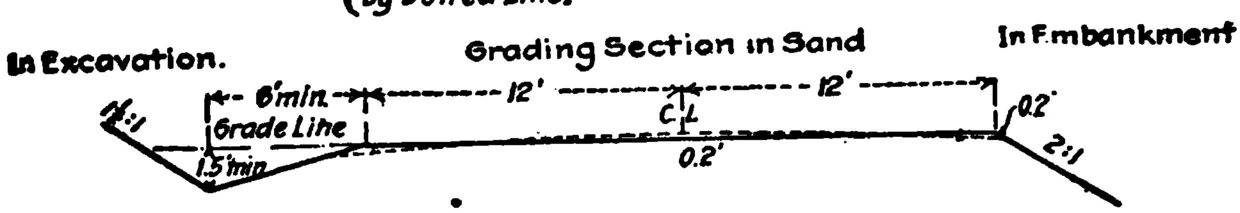


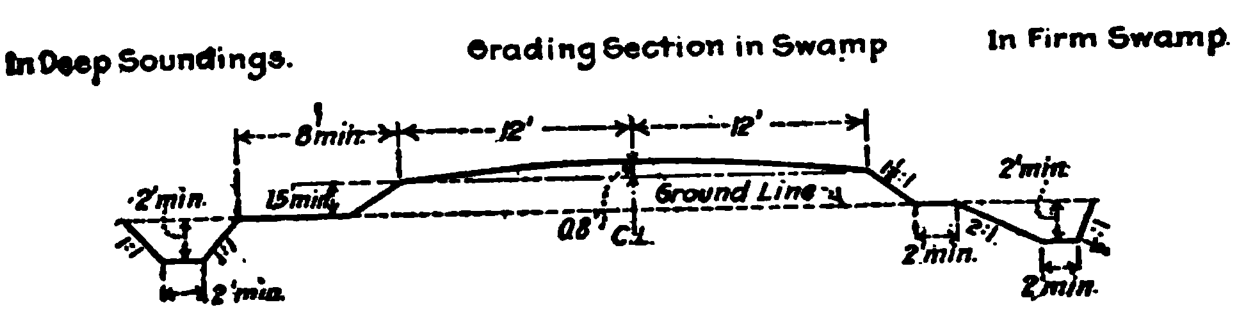
Depth 1st Course	0.00'	0.17'	0.21'	0.25'	0.29'	0.32'	0.29	0.25'	0.21'	0.17'	0.00'	800 Cu.Yd. per Mi.
Depth 2nd Course	0.00'	0.00'	0.09'	0.15'	0.18'	0.18'	0.18	0.15'	0.09'	0.00'	0.00'	400 " " " "
Total Depth	0.00	0.17'	0.30'	0.40'	0.47'	0.50'	0.47	0.40'	0.30'	0.17'	0.00'	1200 " " " "



1st Course	0.00'	0.17'	0.20'	0.23'	0.27'	0.30'	0.30'	0.30'	0.27'	0.23'	0.20'	0.17'	0.00'	1000 Cu.Yd. per Mi.
2nd Course	0.00'	0.00'	0.10'	0.17'	0.20'	0.20'	0.20'	0.20'	0.20'	0.17'	0.10'	0.00'	0.00'	600 " " " "
Total Depth	0.00	0.17'	0.30'	0.40'	0.47'	0.50'	0.50'	0.50'	0.47'	0.40'	0.30'	0.17'	0.00'	1600 " " " "







loaded. No earth, sod or any foreign or vegetable matter, nor an excess of sand or clay, will be allowed in the gravel, and care must be taken that strippings be not mixed with the gravel. Any loads taken to the work containing such objectionable materials will be rejected.

Dumping and Spreading First Course.—The first course material shall be deposited in a uniform ridge on the center line of the road and shall be spread immediately upon the sub-grade to a uniform section. This work shall be started at a point on the road nearest the pit or loading place and shall proceed therefrom until the extreme haul in that direction is reached.

Shaping and Compacting.—The surfacing material shall be shaped, while being compacted under travel by the use of a blade grader, tooth harrow, planer or other suitable means. Ruts formed by the hauling or by travel shall be dragged full at least once each day and more frequently if necessary, to prevent cutting through the surfacing material into the sub-grade. Holes, waves and undulations, which develop and are not filled by dragging shall be filled by adding more material according to the direction of the engineer. The shaping of the material shall be performed according to the direction of the engineer and shall be continued until the material is well compacted, free from ruts, waves and undulations and is made to conform to the cross-section indicated on the standard above mentioned.

If the material is not sufficiently compacted by the above methods within twenty days after placing, the engineer shall direct the character, amount and method of applying the binding material necessary to produce a compacted surface, and the contractor shall provide the necessary labor and equipment to perform such additional work at the unit prices submitted for the application of the regular surfacing material. The County shall furnish this binding material in the same manner as provided for the regular first and second course material.

Second Course.—When the first course is compacted and shaped as specified, to the satisfaction of the engineer, he shall authorize the application of the second course materials. It shall then be applied, shaped and compacted by the methods specified for the first course. The work of shaping and compacting shall be continued until the material is well compacted with the surface free from ruts, waves and undulations and conforming to the specified cross-section.

Maintenance.—Maintenance is discussed in Chapter VII.

Oiling.—Oiling with a light cold asphaltic oil or cold tar is resorted to under a moderately heavy automobile traffic. No gravel road should be oiled till at least a year old so that it is completely consolidated and firmly bound. The surface must be well cleaned of excess fine dust and the oil applied in two or three successive light coats of approx. ⅛ gallon per square yard at intervals of two or three months. It takes more than one application to give even moderately good results as the clay and loam in the road tends to prevent the formation of a good bond between the oil and gravel but if persistent treatment is adopted this method increases the power of gravel roads to withstand touring car traffic but of course does not increase their structural strength or make them suitable for heavy unit freight hauling.

Cost.—Pit run gravel varies in cost from 50c. to $1.50 per consolidated cubic yard in place. Screened gravel from $1.00 to $2.00 per consolidated cubic yard.

Gravel surfacing adds approximately $1000 to $3000 per mile to the cost of an earth road in the same location and a fair comparative price for this type including drainage and incidentals ranges from $2000 to $5000 per mile.

Other Coarse Materials.—The same principles apply to the use of any available local material such as slag, chert, caliche, disintegrated granite, cinders, shell, etc., each one of which can be used to advantage in special localities.

Miscellaneous Special Cases.—Alaskan Climatic and soil requirements afford special problems; the following quotation from Engineering and Contracting of March 6, 1918, indicates an interesting condition as described in the report of the Alaskan Highway Commission.

"The most unusual and troublesome feature encountered in construction is the permanently frozen ground which covers a large portion of the entire interior, and which is protected from thawing during the summer by a thick layer of moss, turf, or decayed vegetable matter. The character of this frozen material varies largely in different sections of the territory, and even in the same section. It may be gravel, clay, silt, peat, or clear ice, or a combination of two or more of these elements.

When gravel is encountered the problem presents no special difficulties; the moss or turf is stripped off, and the road graded in the usual manner. When the material is clay, experience has shown that the same procedure can usually be followed, but the grading is a slow and rather expensive process. After the protective covering of vegetable matter is removed, it is necessary to allow the soil to thaw and dry out somewhat before it can be worked, and unless a considerable period is allowed to elapse between the stripping and the grading, it will be found that the thawing has not extended to sufficient depth to permit of completing the grading in one operation. When the necessity for the road is not pressing, an appreciable saving can be effected by stripping the road bed and digging drainage ditches during one season, completing the construction the next year.

In those localities, however, where the frozen material is silt or peat, the stripping of the roadbed quickly results in the formation of a quagmire through which a man or horse, even without a load, can pass only with the greatest difficulty. Such soil has sufficient bearing value only as long as it remains frozen, which makes it desirable that the moss or turf over-lying it be kept intact. This layer of vegetable matter is not of itself able to sustain traffic, necessitating the addition of a protective covering—usually pole or brush corduroy when timber is available. Fortunately the growth of scrub spruce timber which covers a large part of interior Alaska, except the Seward Peninsula, affords excellent material for this corduroy.

Where the trees are large enough pole corduroy is constructed by grubbing all stumps and roots from the roadbed, leveling it, and laying perpendicularly to the axis of the road a single layer of poles from which the largest and stiffest branches have been trimmed. Ditches are then dug at a distance of 3 to 5 ft. from the ends of the poles, and the material therefrom, after rejecting the top layer of vegetable matter, is placed on the corduroy for the double purpose of protecting it from wear and affording a smoother roadway. If the soil in the ditches is entirely unsuitable for this covering, other material, preferably gravel, is hauled on from the nearest available source.

Where the spruce timber is of very small size, or where only small willows are available, as on the Seward Peninsula, brush corduroy is used. The method of construction is similar to that described above, except that the single layer of poles is replaced by mattress of untrimmed brush containing sufficient material to give a thickness of at least 6 inches when compressed.

When corduroy has been properly protected, its life in most parts of Alaska is quite long. Poles taken out of the road after 10 years of service have been found to be in excellent condition.

The 3 to 5 ft. berm which is left between the ends of the corduroy and the ditches is very necessary to protect the corduroy from undermining, as the ditches, under the action of sun and rain, slough and cut rapidly. Ordinarily, as the frozen soil thaws and cuts away the moss of the berm gradually assumes a gentle slope to the bottom of the ditch, effectually protecting the corduroy, but where the cutting is severe, it often becomes necessary to revet the insides of the ditches with moss or turf. Frequent outlets from the ditches must be provided, and when the amount of water reaching the ditch on the upper side of the road is large it is advisable to construct an additional ditch parallel to the road and about 50 ft. away, with sufficient outlets to culverts of ample size.

Along the Pacific coast of Alaska no frozen ground is encountered, but the mountainous character of the country, the excessive rainfall, and the difficulties of clearing, have made the work, as a rule, even more expensive

than in the interior. Unless the soil encountered in this region is gravel, it will not stand up under traffic during the heavy and continuous rains, and some protective covering is required. Fortunately gravel is usually found at no great distance; otherwise corduroy or plank roads are constructed.

The numerous swift streams of glacial origin found in the Pacific coast section and throughout the Alaskan range in the interior have been the source of much trouble and expense. Flowing through gravel beds varying in width with the volume of water carried up to 2 miles or more, they rarely have any fixed channels. It is by no means uncommon for one of these streams to abandon an old channel and establish itself in a new one ½ mile away almost over night. When warm weather causes rapid melting of snow and ice in the glaciers, these streams become raging torrents of enormous destructive force, and roads paralleling them are in constant danger of being washed away. Numerous methods of bank protection to prevent damage from this cause have been tried, of which the following has proved to be the cheapest and most effective: A layer of loose brush of sufficient length to give the requisite protection is placed on the threatened bank, perpendicular to the current and weighted below the center with stone enveloped in galvanized-wire netting, the whole being anchored in place by wires extending to "dead-men." For emergency work when the water is too high to permit of placing the wire netting and rock, the brush is made into fascines inclosing sacks of earth, which are then placed against the threatened bank and wired to it and to each other. This form of protection is easily and quickly constructed and has repeatedly demonstrated its effectiveness.

As now constructed, the width of wagon roads varies with the formation of the ground and the amount of traffic expected, but as a general rule roads graded by other means than the road grader are given a minimum width of 20 ft. between ditches, and those on which the road grader is used a minimum width of 24 ft. On steep sidehills and where rock work is involved, the width is reduced to 10 or 12 ft. The standard width of clearing is 30 ft. but this is increased to 60 ft. where necessary in order to secure the beneficial action of wind and sun on the roadbed.

Sled roads for winter traffic only are cleared for a width of 16 ft., with all stumps, hummocks and similar obstacles removed for a width of 8 ft. They are constructed where the amount of traffic is not great enough to justify a wagon road, where the cost of building a wagon road would be prohibitive, or where the communities along the route are amply served by water transportation during the open season, as is the case with the Fairbanks-Fort Gibbon sled road. If it seems probable that future development may demand or justify a wagon road, the location is made as for a wagon road, in order that work done on the sled road may be of use when the improvement is made.

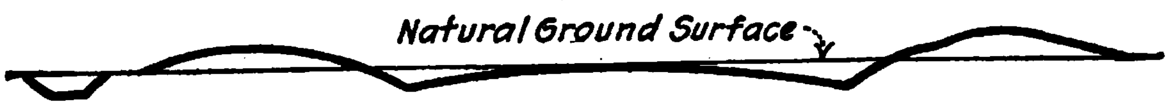
Trails designed for travel by dog team in winter or by pack train in summer are given a width of 8 ft., with all stumps and underbrush cutoff as close to the ground as possible.

In the past, the work of constructing and gradually improving the roads has been so generally intermingled with maintenance operations that a systematic plan for maintenance has not been put into effect, nor would such a plan have been feasible in view of the uncompleted state of the roads. At the present time, however, the condition of parts of the more important roads, notably the Valdez-Fairbanks Road, is such as to make practicable their maintenance by dragging. As Alaska has only a very small agricultural population, the method adopted in many states of contracting with farmers adjacent to the road for the necessary dragging can not be used, but it is intended to place on completed sections small maintenance crews consisting, as a rule, of two men each, supplied with a team, wagon, drag, and the necessary small tools. Two such crews have been employed on the Valdez-Fairbanks Road during the present summer, with very satisfactory results. On several of the gravel-surfaced roads in southeastern Alaska the patrol system of maintenance has been used in connection with more extensive repairs. The results show the method to be very effective for roads of this character.

The average costs per mile, including construction and maintenance of all roads and trails constructed by the board since its organization in 1905 are as follows: Wagon road, $3,419; sled road, $379; trail, $113. A division of these amounts to show the exact cost of construction proper is impossible, but a careful analysis of the available data indicates that the following unit costs of construction, including bridges, may be accepted as approximately

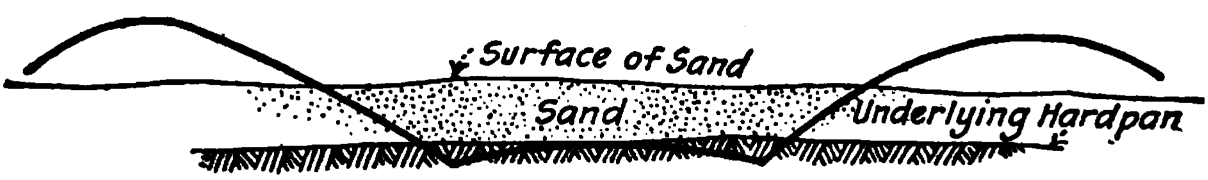
correct: Wagon roads, $2,475 per mile; sled roads, $300 per mile; trails, $65 per mile. The average costs of maintenance during the past season were as follows: Wagon roads, $250 per mile; sled roads, $14 per mile; trails, $8 per mile."

Arid Regions.—In the arid regions fills must be avoided. Ordinary earth roads are constructed below the general elevation of the ground as follows:



which keeps them moist longer; shallow ditches are used for the same reason. In many cases a hardpan formation underlies the sand surface and in these conditions the sand surface is scraped off and the road built on the underlying strata.

Where fills must be used they should be made during the rainy season and the addition of clay to a sandy soil helps consolidate the traveled way. Readers are referred to the reports of the



State Engineers of New Mexico and Arizona for further data on the special treatment of roads under these conditions.

Summary of Chapter.—Roads of the type discussed in this chapter form the groundwork of future high-class pavements and represent the greater percentage of mileage of roads in this country. They are entitled to more engineering supervision than they have received in the past.

CHAPTER V

GRAVEL AND STONE FOUNDATION COURSES FOR HARD SURFACED PAVEMENTS

Concrete foundations are considered under "Rigid Pavements" in Chapter VI.

The real foundation of a road is the earth sub-grade; generally, however, the term foundation is used in speaking of the lower course of stone, gravel, etc., used to help distribute the concentrated wheel loads. A discussion can be developed under the following heads.

1. The bearing power of different soils.
2. The concentrated wheel loads on improved roads.
3. The distributing action of foundation courses and the depth required for different soils.
4. The different kinds of foundation courses.
5. The distribution of the stone in the foundations.
6. Special cases.

1. Bearing Power of Soils

The sub-grade develops its greatest bearing power when dry. In the following discussion we assume that the soils are protected by a well designed drainage system.

Mr. W. E. McClintock, Mem. Amer. Soc. C. E. Chairman of the Massachusetts Highway Commission, published in the 1901 report of the Commission a valuable statement of the results of their investigations on the bearing power of soils and the distribution of wheel loads by the macadam.

"The Commission has estimated that non-porous soils, drained of ground water, at their worst will support a load of about 4 lb. per square inch; and having in mind these figures the thickness of broken stone has been adjusted to the traffic.

"On a road built of fragments of broken stone the downward pressure takes a line at an angle of 45 degrees from the horizontal and is distributed over an area equal to the square of twice the depth of the broken stone. If the division of the load in pounds at any one point by the square of twice the depth of the stone in inches gives a quotient of four or less, then will the road foundation be safe at all seasons of the year. On sand or gravel the pressure can be safely put at twenty pounds per square inch.

"Acting on this theory the thickness of the stone varies from four inches to sixteen inches, the lesser thickness being placed over good gravel or sand, the greater over heavy clay, and varying thicknesses on other soils. In cases where the surfacing of broken stone exceeds six inches in thickness, the excess in the base may be broken stone, stony gravel or ledge stone; the material used for the excess depending entirely upon the cost, either being equally effective."

It will be noted that the values of the safe bearing power of soils are well under those used for building foundations. The depths however are not enough for modern traffic as will be discussed later. For purposes of convenient reference traffic is classified on page 164 and will be referred to as Classes I, II, III and IV.

2. Concentrated Wheel Loads

There should be some limit placed by law to the maximum load per lineal inch of tire for vehicle using improved roads. The roads can then be designed for this load with no danger of failure from unreasonable pressures. Road work is handicapped in this country by the lack of wide tire statutes and the regulation of traction engines using sharp lugs on the wheels. At present it is necessary to assume a loading that will probably not be exceeded by the unregulated traffic. Many engineers favor a law limiting the load on improved roads to 700 to 800 lb., to the lineal inch of tire width, which is a reasonable limit; with a six inch thread this would mean a load of nine tons for a four wheel wagon provided the load was uniformly distributed. This is beyond the limits of team hauling.

Most of the mechanical trucks in present use have tires wide enough to reduce the pressure below this limit. Near some of the large cities, however, mechanical trucking has increased to proportions that amount to a regular freight line and excessive loads are carried; the load and speed for such trucks must be regulated, for no road can stand abuse of this character. In special metropolitan districts where truck freighting is desirable to relieve rail congestion or where it is economical by means of its direct loading and delivery, specially designed toll roads, which are self supporting financially, could be built to handle much heavier loading, but for free public use roads, maintained by the community, a gross vehical load of 12 tons is a reasonable limit.

The following regulations governing the control of motor trucks and traction-engines were prepared by the New York State Highway Commissioner to go into effect in 1914.

Regulations for State and County Highways Adopted by the Commissioner of Highways of the State of New York

Section 1.—No traction-engine, road-engine, hauling-engine, trailer, steam-roller, automobile truck, motor or other power vehicle shall be operated upon or over the state or county highways, the face of the wheels of which vehicle are fitted with flanges, ribs, clamps, cleats, lugs or spikes. This regulation applies to all rings or flanges upon guiding or steering wheels of any such vehicle. In case of traction-engines or hauling-engines which are equipped or provided with flanges, ribs, clamps, cleats, rings or lugs, such vehicle shall be permitted to pass over said highways provided the cleats are fastened upon all the wheels of such vehicles, and are not less than 2½ in. wide and not more than 1½ in. high, and so placed that not less than two cleats on each wheel shall touch the ground at all times, and the weight shall be the same on all parts of said cleats.

SECTION 2.—No traction-engine, trailer, steam-roller, automobile truck, motor or other power vehicle shall be operated upon or over the state or county highways; nor shall any object be moved over or upon any such highways upon wheels, rollers or otherwise, in excess of a total weight of 14 tons, including the vehicle, object or contrivance and load, without first obtaining the permission of the State Commission of Highways as hereinafter provided. No weight in excess of 8 tons shall be carried on any one axle of any such vehicle.

SECTION 3.—The tire of each wheel of a traction-engine, road-engine, hauling-engine, trailer, steam-roller, automobile truck, motor or other power vehicle (except traction-engines, road-engines, and hauling-engines) shall be smooth, and the weight of such vehicle, including load, shall not exceed 800 lb. upon an inch in width of the tire, wheel, roller or other object, and any weight in excess of 800 lb. upon an inch of tire is prohibited unless permission is obtained from the State Commissioner of Highways as hereinafter provided.

SECTION 4.—No motor or other power vehicle operated upon any state or county highway shall be of a greater width than 90 in., except traction-engines which may have a width of 110 in.

SECTION 5.—No traction-engine, road-engine, hauling-engine, trailer, steam-roller, automobile truck, motor or other power vehicle, carrying a weight in excess of 4 tons, including the vehicle, shall be operated upon any state or county highway at a speed greater than 15 mi. per hour; and no such vehicle carrying a weight in excess of 6 tons, including the vehicle shall be operated upon any such highway at a speed greater than 6 mi. per hour when such vehicle is equipped with iron or steel tires, nor, a speed greater than 12 mi. per hour when the vehicle is equipped with tires of hard rubber or other similar substance.

SECTION 6.—The State Commissioner of Highways, upon proper application in writing, may grant permission for the moving of heavy vehicles, loads, objects, or structures in excess of a total weight of 14 tons over state and county highways, upon proper application in writing being made therefor, and under such restrictions as the Commissioner may prescribe.

SECTION 7.—The owner, driver, operator or mover of any vehicle over any state or county highway shall be responsible for all damages which said highway may sustain as a result of a violation of any of the provisions of the foregoing Rules and Regulations, and the amount thereof may be recovered in an action of tort by the State Commissioner of Highways or by any County Superintendent of Highways of any county or by any Town Superintendent of Highways of any town in which said violation occurs.

1. SECTION 8.—These regulations take effect October 20, 1913.

"Section 24 of Chapter 25 of the Consolidated Laws entitled 'The Highway Law' provided that any disobedience of any of the foregoing rules and regulations shall be punishable by a fine of not less than $10 and not more than $100 to be prosecuted by the Town, County or District Superintendent, and paid to the County Treasurer to the credit of the fund for the maintenance of such highways in the town where such fine is collected."

Under these regulations properly enforced any of the ordinary foundation courses can be successfully used provided the depth is varied to meet the soil condition.

Military Loads.—Major General W. M. Black, Chief of Engineers, gives the following information on the loads military roads must be expected to carry.

"Our existing ordinance liable to accompany a field army will have its heaviest representative in a 12-in. howitzer weighing about 27,000 lb., 18,600 lb. of which are on the front wheels. The base or distance between the front and rear axles is 18 ft.; width of track 7 ft. 4 in.; width of tire, 8 in.; width of tire shoes, 12 in. This howitzer is to be drawn by a 75 h.p. caterpillar tractor weighing 25,000 lb. Comparison with the largest present-day commerical trucks shows that a road substantial enough for such will suffice for the ordinance load, so that in this particular, as well as in a strategic way, roads suitable for commercial purposes will meet the military requirements."

Secretary of War Baker gives the following requirements for military roads:

"The following requirements as to construction within the areas mentioned are recommended: (1) Road to have a smooth, hard surface of broken stone or a pavement not less than 20 ft. in width and capable of supporting the loads hereinafter specified for bridges; (2) grades not to exceed 5 per cent., except for short distances (less than 50 yd.) where they shall not exceed 10 per cent.; (3) bridges to be of iron or masonry and of type to support loads of a 6 in. howitzer (3000 lb. on front wheels and 6500 lb. on rear wheels, distance between axles 12 ft., width of wheel track 5 ft.) or a 3 ton truck loaded (6000 lb. on front wheels, 8000 lb. on rear wheels, distance between axles about 10 ft., width between wheels, center to center, about 5 ft.). In hilly country, where road foundations are necessarily hardpan or rock, the importance of artificial surfacing is less important than the completion of a well drained roadbed joining the roads in the adjacent valleys; and it is therefore recommended that in such cases the completion of an unsurfaced graded road be completed before the requirement as to artificial surface is enforced."

Commercial Loads.—Records of produce dealers show that heavily loaded farm wagons weigh about 5000 lb. of which about 0.6 is on the rear axle. The rear wheels carry approx. 1500 lb. on 3 to 3½" tires and allowing for 25% impact exert a pressure of approx. 600 lb. per linear inch of tire. Large modern trucks[1] loaded weigh about 10 tons and carry approximately three-fourths of the weight on the rear axle. Each rear wheel is generally equipped with two six inch rubber tires and exert a pressure of approximately 700 lb. per linear inch. The author believes that a road designed for a 5 ton load on a 12" tire or at the rate of 800 lb. per linear inch should be safe.

NOTE.—The length of wheel bearing on a well constructed macadam road is about 1".

The use of this loading and the application of the rules for distribution of pressure given by Mr. McClintock in the preceding quotation results for "Main Roads" (Class II and Class IIA traffic, see page 164) subjected to heavy frost action in northern climates, in a total consolidated depth, including top course, of 9" on fine gravel or coarse sand and 22" on wet heavy clay or fine loam of which more than 30% passes a No. 100 sieve. For feeder roads (Class III traffic) in northern states and for Class II traffic in climates free from frost these depths can be safely reduced to 5" to 7" on gravel and 15" to 20" on clay.

The thickness to be used in the intermediate cases must depend on the judgment of the engineer. The following examples are intended only as a guide for the more common cases for roads on which the traffic makes a macadam design reasonable. The amount for special cases often depends on trial.

Coarse sand and gravel require from 5" to 9". New York State uses 7" as a minimum. Massachusetts uses the following section on good gravel (Fig. 28).

Wherever the stone is less than 6" it should be laid in one course and classified as top stone.

[1] Pierce Arrow 5 ton trucks have the following specifications (1918).

Maximum body width, 7'	Weight of chassis, 7800 lb.
Wheel base, 14' to 17'	Body, 2500 lb.
Gage, 69"	Net load, 10,000 lb.
Two 6" tires on each rear wheel.	75% of net load on rear wheels.
	Total weight of truck loaded, 20,000 lb

For a light clay loam an average depth of 9″ to 12″ is sufficient in cut; for fills over 2′ deep 9″ is enough; high fills even of clay often having once settled rarely give trouble with 9″ of stone.

Heavy clay requires at least 15″ in cut; if the soil is springy or especially poor 18″ to 24″ is advisable.

For shallow fills see Figure 29.

In shallow or "pancake" fills, clay or fine sandy loam should never be used where the natural surface at this point is of a better

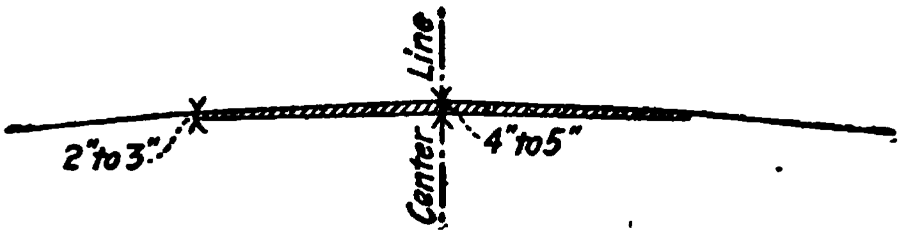


FIG. 28.

variety, as they are almost certain to become saturated with water and will either squeeze or heave out of shape; long shallow fills are to be avoided, which is considered in laying the grade line, but where unavoidable, the best available material should be obtained and the original surface well broken up to form a bond with the new fill. Where clay is used it should be treated as in cut. For clay fills of intermediate depth (1 to 2 ft.) a stone depth of 10″ to 12″ is satisfactory.

FIG. 29.

To illustrate the different stone depths that may be used in a short distance an extract follows from the construction report on foundations for "Clover Street Sec. 1" a road near Rochester, New York. This was built in 1907–1908 and has held satisfactorily under farm traffic (Class III).

Clover Street Road, Section 1

The normal depth of stone on this road was 7″—3″ top, 4″ bottom.

Station to Station		Character of Sub-grade	Total Depth of Stone
180	183 + 25	Cut in sand and gravel	6″
183 + 25	186 + 25	Clay fill	8″
186 + 25	187	Light Clay cut	11″
187	190	Sand, gravel and clay	7″
190	191	Ordinary Clay cut	12″
191	193	Clay loam fill	7″
193	200	Sand and gravel	6″

A summary of recommended consolidated depths of macadam construction for different soils in cut and fill is given below.

TABLE OF TOTAL CONSOLIDATED DEPTHS OF MACADAM

Sub-grade Soil	Cut	Shallow Fills Less Than 1′ Deep	Intermediate Fills 1 to 3′ Deep	High Fills Above 3′ Deep
Class I Traffic — Large volume of ordinary vehicles and heavy auto trucks				
Coarse sand and fine gravel	9″	9″	9″	9″
Clay loam	12″ to 15″	12″ to 15″	10″ to 12″	10″
Heavy clay and quicksand	20″ to 24″	20″ to 24″	12″ to 18″	10″
Class II Traffic — Large volume ordinary traffic. A few heavy trucks				
Sand and gravel	7″ to 8″	7″ to 8″	7″ to 8″	7″ to 8″
Loam	9″ to 12″	9″ to 12″	9″	8″
Clay and quicksand	15″ to 22″	15″ to 22″	12″ to 15″	9″
Class III Traffic — Moderate volume ordinary farm loads. Very few heavy trucks				
Sand and gravel	5″ to 8″	5″ to 8″	5″ to 8″	5″ to 8″
Loam	8″ to 12″	8″ to 12″	8″	7″ to 8″
Clay and quicksand	15″ to 22″	15″ to 22″	10″ to 15″	9″

NOTE.—Under Class III traffic it is better to use the same depth as recommended for Class II and reduce the width of metaling if economy is desired, as all improved roads are bound at times to be subjected to the extreme loading produced by heavy trucks.

Preparation of Sub-grade

It is evident from the pressures to which a road is subjected that the sub-grade must be well consolidated before placing the foundation stone. This is usually effected by rolling with a 10 or 15 ton steam roller, exerting a pressure of 350 to 500 pounds per linear inch or wheel width, and is continued until the grade is firm and compact.

The difficulties of consolidation in different soils and the methods of overcoming them will be included in Chapter XV.

KINDS OF FOUNDATION COURSES

The foundation courses in ordinary use are as follows:

1. Crushed stone.
2. Screened gravel.
3. Field stone sub-base.
4. Pit gravel sub-base.
5. Field stone sub-base bottom course.
6. Pit gravel sub-base bottom course.
7. Quarry stone base or Telford.

1. **Broken Stone Bottom Course.**—This style of construction is the one in most general use. Where local stone is abundant and well distributed, such a course will cost[1] from $2.00 to $2.50 per cubic yard rolled in place; where imported stone is necessary, the cost depends largely upon the freight rate and the length of haul and may run as high as $5.00. Bottom of this kind is generally used where the total depth of stone metaling does not exceed 6″ to 8″ after rolling. Beyond these depths it is often cheaper to substitute sub-base or sub-base bottom course for a part or the whole of the broken stone course.

The method of construction by the New York State Highway Commission is shown in the following extract from their 1911 specifications:

Stone Macadam Bottom Course

"After the sub-grade has been prepared and has been accepted by the engineer, a layer of broken stone of the approved size and quality for bottom course shall be spread evenly over it to such a depth that it shall have, when rolled, the required thickness. The depth of the loose stone shall be gaged by laying upon the sub-grade cubical blocks of wood of the proper size and spreading the stone evenly to conform to them."

"The roller shall be run along the edge of the stone backward and forward several times on each side before rolling the center. Before putting on the filler the course shall be rolled until the stone does not creep or weave ahead of the roller. In no case shall the screenings or sand for filler be dumped in mass upon the crushed stone, but they shall be spread uniformly over the surface from wagons or from piles that have been placed on the shoulders. It shall then be swept in with rattan or steel brooms and rolled dry. This process shall be continued until no more will go in dry, when the surface shall, if required by the engineer, be sprinkled to more effectually fill the

[1] All costs are for comparative purposes and are based on 1912–1914 conditions.

voids. No filler shall be left on the surface, and the bottom course stone shall be swept clean before covering with top course. Only such teaming as is necessary for distributing the materials will be allowed on the bottom course. Any irregularities or depressions, the result of settlement, rolling or teaming, if slight, shall be made good with broken stone of the same size used in the bottom course, otherwise the stone shall be removed and the sub-grade regraded and rolled. Such removal and restoring of the surface shall be made at the expense of the contractor. Screenings shall not be used in leveling up irregularities or depressions."

Massachusetts used no filler; otherwise their construction is substantially the same as New York.

Where imported stone is specified or the local stone is suitable for both top and bottom courses, the size used for bottom course is known commercially as "No. 4 stone" and ranges from 2¾" to 3¾" in its greatest dimension; the smaller size is used for the top course, for concrete and for filler; where the local material is only fit for bottom, the course is made up of stone ranging from 1" to 3¾" in order to use up the total output of the crusher. The stone smaller than 1" is used for filler, on the shoulders, and sometimes for the cheaper grades of concrete. In specifying the sized stone for a particular job, economy is considered. Stone sized from 1" to 3¾" is perfectly satisfactory. The only reason for limiting the usual size from 2¾" to 3¾" is that it leaves the 1" to 2¾" stone for the top course; a uniform grade is important for the top and the size mentioned gives a smooth finish.

The ratio of loose depth to rolled depth is given on page 591.

Where filler is not used in the construction of the bottom course more binder is required for the top; it is our opinion that the use of filler is the better construction but it must be of good quality.

The clause concerning teaming in the quoted specifications is a dead letter; teaming helps to consolidate the bottom provided it is distributed over the full width and care is taken in watching the course to prevent loss of shape when the traffic is first turned on or after a long continued rainfall.

2. **Screened Gravel Bottom Course.**—Screened gravel 1" to 3½" in size is used in place of crushed stone; the course is constructed in the same manner as described above, except that a filler containing some clay or clay loam is preferable to a coarse sand, and it is often necessary to wet the course in order to consolidate it satisfactorily. It is also necessary to apply the filler before the course is rolled.

A gravel bottom should be made somewhat thicker than a crushed stone bottom as the fragments do not interlock as firmly as crushed stone.

The choice between a screened gravel or crushed stone bottom depends entirely on the relative cost. Under favorable conditions a screened gravel bottom course will cost from $1.30 to $2.00 per cubic yard, rolled in place. A course pit run gravel is preferable to a screened gravel bottom.

3. **Field Stone Sub-base.**—Field stone sub-base is constructed, as shown in the cut, of field boulders roughly placed and filled with gravel, waste No 2 stone or stone chips; no attempt is made to

finish the top of the course exactly to line and grade, as any small inequalities can be filled with bottom stone. The depth varies from 5″ to 20″ depending on the soil encountered and the size of the available field stone. In designing a bottom course of this kind, care must be taken to have accurate data as to the average size of stone available. If the demands of a foundation were fully satisfied by a 5″ sub-base course, it might still be more economical to use a 7″ course if the stone averaged seven inches, because the extra work of sorting and sledging to a 5″ size would result in a higher cost per square yard than for a 7″ depth.

The amount of stone and filler required per cubic yard in place is given on page 591.

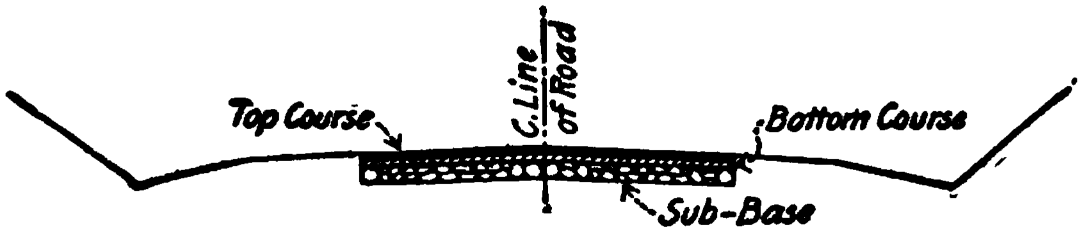


FIG. 30.

Under favorable conditions this sub-base can be constructed for $1.00 to $1.50 per cubic yard.

4. **Pit Gravel or Creek Gravel Sub-base.**—Stony gravel is a satisfactory material for sub-base; it can be readily constructed for any depth from 2″ to 24″ if required, and where a pit or creek bar is near, the cost of such a course should run from $0.80 to $1.25 per cubic yard.

The ratio of loose to consolidated gravel for such a course is given on page 591.

5. **Field Stone Sub-base Bottom Course.**—Sub-base bottom course is essentially the same construction as sub-base, except that, as the top course is placed directly upon it, the stone must be more carefully assorted as to size, more carefully placed as to line and grade, and a better grade of filler must be used.

Crushed stone (crusher run) or coarse gravel make a satisfactory filler.

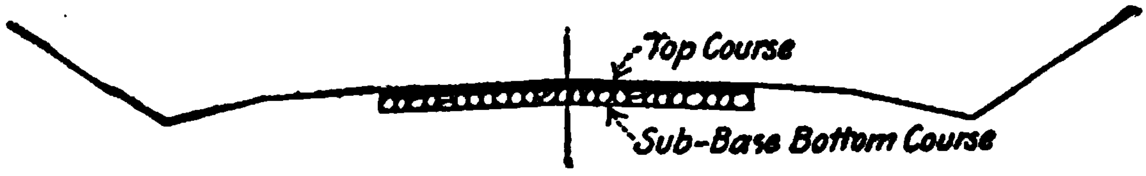


FIG. 31.

The course can be of any depth from 5″ up, depending, as for sub-base, on the soil and average size of stone; it is practically impossible to make a large stone bottom of this kind conform exactly to line and grade; a variation of 1″ either above or below grade is usually allowed and the inequalities taken out with the top stone; this requires that the top course must be at least 3″ deep after rolling.

Sub-base bottom is especially applicable for long stretches of road requiring a depth of 9″ to 20″; it usually costs from $1.30 to $1.70 per cubic yard in place where fence stone is available, and by its use the item of higher priced bottom stone is reduced. However, on a hard foundation it is generally better to use 4″ to 5″ of ordinary broken stone bottom course instead of the sub-base bottom course even if more expensive, because the small stone construction is more uniform in its resistance to heavy loads and the top course will wear more evenly and longer.

An extract from the 1915 New York State Specifications is given below:

Sub-base Bottom Course

When field or quarry stone is used for constructing the foundation course it shall be of a hard, sound and durable quality, acceptable to the engineer; the stone shall be placed by hand so as to bring them in as close contact as possible. When quarry stones are used they shall be placed on edge. The depth of the stone shall in no case be greater than the depth specified for the course, the width shall not be greater than the depth, nor more than 6 inches, and the length shall not be greater than one and one-half times the depth, nor more than 12 inches. The distribution of the stone shall be of a uniformity satisfactory to the engineer. The long dimension shall always be placed crosswise the road. After laying, this course shall be thoroughly rolled with an approved roller weighing not less than 10 tons, and shall then be filled with stone or coarse gravel as directed and again rolled until the stones are bound together and thoroughly compacted; but no gravel shall be used for filling except under written permission of the engineer. All holes or depressions found in rolling shall be filled with material of the same quality and the surface shall be rerolled until it conforms to the lines and grades shown on the plans. When field stone is used approved tailings may be used for filling. In all cases a sufficient amount of fine material shall be used to fill all voids. In limited areas where the use of a roller is impracticable heavy tampers may be used to consolidate the material.

6. **Pit Gravel Bottom or Sub-base Bottom.**—A stony gravel containing not over 15% of loam makes a satisfactory course; the depths vary from 4″ to 18″; pit or creek gravel even when unusually coarse has from 40 to 60% of fine material; a suitable gravel for pit run bottom should not contain more fine material passing a ¼″ screen than coarse material retained on a ¼″ screen. If there is a large excess of fine the gravel should be screened and remixed at the bin in proper proportions.

The great difficulty in this construction is to get proper consolidation without too much delay. It is advisable to lay a course of this kind at least two weeks ahead of the top stone in order to give traffic and rains a chance to help consolidate the course. The addition of 10% of loam to clean gravel will quicken the consolidation. This can be done either at the pit by leaving a thin layer

of loam when stripping which runs down with the gravel in loading or by placing from ½" to 1" of loam on top of the gravel as spread on the road; the author has succeeded in getting rapid consolidation by snatching loaded teams over the loose course with the road roller; the roller continually smooths out the gravel and eases the haul for the teams; the horses' hoofs and wagon wheels punch into the gravel and pack it down rapidly. Sprinkling helps. A gravel bottom consolidates unevenly and it is always necessary to reshape it somewhat after consolidation; about $0.05 per cubic yard should be allowed for this reshaping of crown and elimination of humps and hollows. A properly consolidated gravel bottom will permit a 4 ton load on 3½" tires passing over it without making a wheel mark over ⅛" deep; this is a simple available construction test. We have gone into some detail covering this construction as it is the most economical type of bottom in a large number of cases but is not generally favored because it is harder to consolidate than the other types of bottom. With a 3" or preferably a 4" macadam top it has proved perfectly satisfactory on all but the heaviest traffic roads.

The cost of a gravel bottom ranges from $0.80 to $1.50 per cubic yard in place provided the hauls are short.

The depths of gravel is gaged by blocks or lines and the ratio of loose to rolled depth is approx. 1.2 (see page 591).

7. **Telford Base.**—Telford base is rapidly going out of use in the United States because of the difficulty of maintaining a top course laid upon it. It seems to be too rigid and is more expensive than sub-base or sub-base bottom course, costing about $1.80 to $2.00 per cubic yard under favorable conditions.

A good description of a telford construction is given by Mr. William Pierson Judson in "Roads and Pavements." The following quotation is an extract from his book.

"On this sub-grade are then placed by hand the stones forming the telford foundation, which may vary in size as shown below; each stone must be set vertically upon its broadest edge, lengthwise across the road and forming courses and breaking joints with the next course, so as to form a close and firm pavement. The stones are then bound by inserting and driving stones of proper size and shape to wedge the stones in their proper position. All projecting points are then broken with a sledge or hammer so that no projections shall be within four inches of the finished grade line.

"The telford foundation is then rolled with a steam roller of ten or more tons weight, until all stones are firmly bedded and none move under the roller. All depressions are then filled with stone chips not larger than two and one-half inches, and the whole left true and even and four inches below the line of finished grade and cross-section.

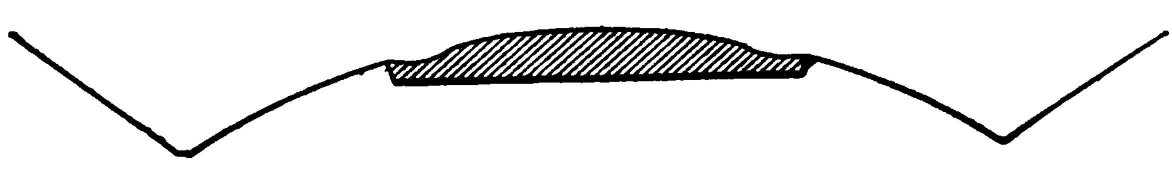
"A good workman will average about twenty minutes in setting a square yard of this telford foundation, which may be formed of any kind of quarried rock which is most available.

"The practice in 1901 in the states named is here shown."

TABLE 21A.—SIZES OF STONE FOR TELFORD FOUNDATION, IN INCHES

State	Depth as Set on Edge		Width as Set		Length Set Across Road		Remarks
	Max.	Min.	Max.	Min.	Max.	Min.	
New Jersey..	8	8	4	—	10	—	Alternate end stones double length.
Mass.......	6	5	10	4	15	6	Two inches gravel rolled on subgrade as base.
Conn.......	8	8	10	6	18	8	Macadam covering formed in one layer.
New York..	8	6	10	4	15	6	Used only on unstable ground as foundation for macadam.

Distribution of Stone in Foundations.—In the discussion of sections, Table 10, page 37, shows that most of the traffic normally keeps to the middle 10′ to 12′. It would therefore appear logical to make the central portion of the road thicker than the sides. This applies without doubt to roads of moderate traffic where the teams generally travel in the center of the macadam and only occasionally turn out to pass but for heavy traffic double track roads



this idea is wrong. On such roads the greatest wear and heaviest wheel load occur about 1 ft. from the edge of the hard pavement and many of these roads develop the shape shown in the above sketch. It therefore seems advisable to keep the full depth of metaling for the full width on Class I and Class II traffic roads.

For Class III traffic the varying thickness indicated in Figures 32 and 33 is applicable.

Figure 32 is an example of such a foundation course for ordinary soils as used by the New York State Highway Commission in 1910.

Figure 33 is an example of an economical sub-base, for a light traffic road as used by the Illinois Highway Commission in 1910.

Special Cases.—Long stretches of comparatively level ledge rock, muck and vegetable loam may be placed under this head.

Where a road is on the surface of ledge rock for any distance, the usual cross-section of part cut and part fill can not be used because of

the high cost of shallow rock excavation for ditches; the grade should be lifted to make the normal section fill and the best available material (not clay) used in its construction. Where conditions of this kind prevail, dirt is usually hard to obtain and often a stone fill is cheaper and also more satisfactory.

The construction shown (Fig. 34) was used for a stretch of two and one-half miles on the Leroy-Calendonia State Highway in New York, where ledge rock was encountered as described.

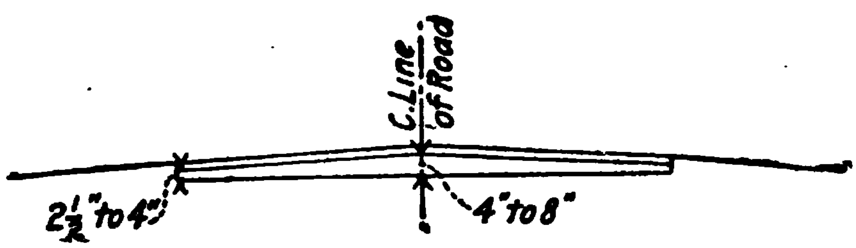


FIG. 32.

The price for the stone fill was $1.23 per cubic yard in place constructed as shown; the road was built in 1910 and has given satisfaction; the minimum thickness of top for such a fill is 3″ as it is impossible to construct it exactly to line and grade; it was found that by allowing a variation of 1″ either above or below the grade elevation, the fill could be readily constructed, and these small inequalities were taken out with the top stone. A top course having such a variable thickness should be paid for by weight and not by volume in place (see page 586, "Cost Data").

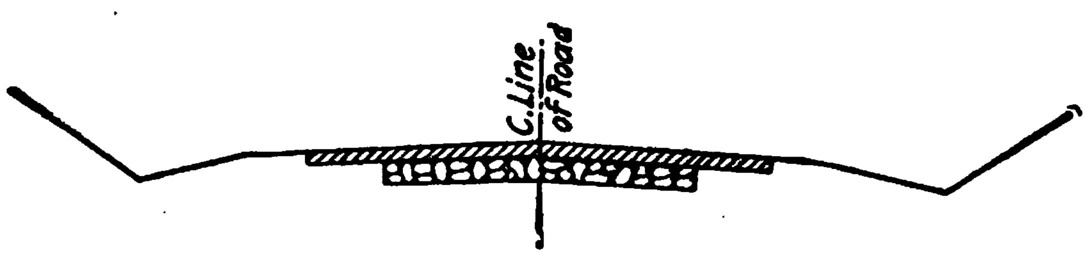


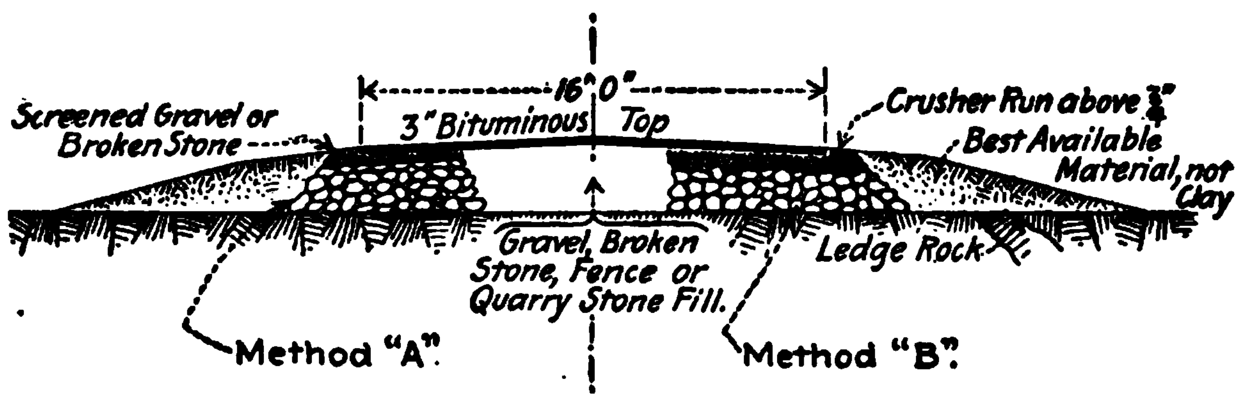
FIG. 33.

Peat, Muck, Vegetable Loam, or Silt.—Where the material is semifluid the only solution is a pile and grillage foundation.

Swamps, as ordinarily encountered, can be treated successfully by using a corduroy or mattress foundation covered with a deep fill of gravel or large stone. In some cases where the muck is comparatively stiff, a gravel or boulder fill alone will give a satisfactory foundation.

Where swamps are crossed by improved roads, the location usually follows the old road which has often been corduroyed in the past; in such cases the old foundation should not be disturbed; a sufficient additional depth of stone can be added to keep the shape of the section intact.

As an example, the Scottsville-Mumford New York State improvement crossed a 1000 ft. stretch of muck on the old road location; it was found that the original cedar corduroy was in good shape; an 18″ depth of large boulders was placed on the old foundation and surfaced with 6″ of broken stone macadam. This stretch of road has kept its shape and has not settled, it affords a good example of the statement made on page 150 that in many special cases the depth of the stone is determined by trial; the boulders were put on in successive layers of 6″ each until there was no material movement under the roller and then surfaced with the broken stone macadam.



Fill can be made of fence stone, gravel, quarry spalls, stone chips, or run of crusher stone over ¾″ in size.

Method A.—Boulders up to 2 cu. ft. can be used, placing the largest in the bottom of the fill; the top layer must be fairly uniform and not over 8″ in size and must be roughly placed by hand to reduce the voids as much as possible, provided this layer of large stone is within 4″ of the bottom of the top course. The top 8″ to be filled with stone chips or gravel and a cushion of at least 2″ of screened gravel, stone chips or crusher run of broken stone over ¾″ in size to be placed on top to bring the fill to the correct grade and crown for the top course.

Method B.—Same materials and manipulation as Method A, except that provided the top of the boulder fill is more than 4″ from the bottom of the top course the top layer of the boulder fill need not be placed by hand (see sketch, Method B).

FIG. 34.

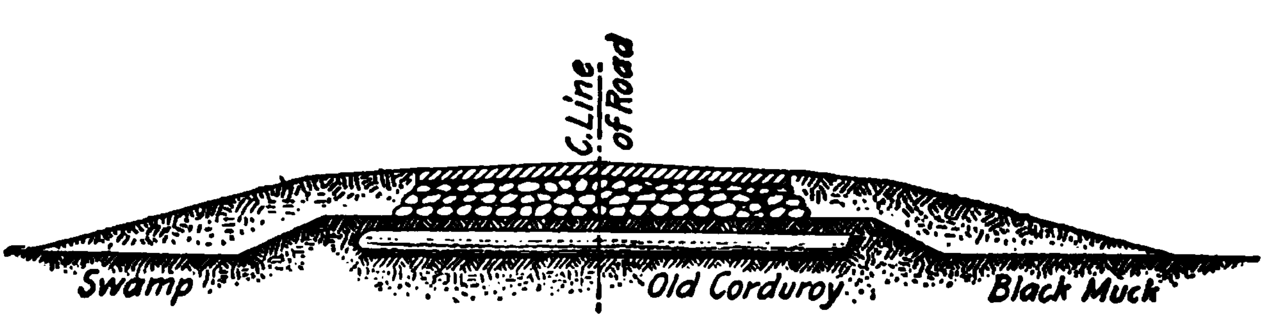


FIG. 35.

Under a heavy load the whole roadbed will vibrate for 100 ft., but the shape remains intact.

Economical Foundation Design Macadam Roads.—The economical design of foundation courses may be summarized as follows:

For moderate traffic use pit run coarse local gravel if available varying the depths to suit the soil. If gravel is not available use a macadam bottom for ordinary soils and field stone sub-base or sub-base bottom for bad foundations. The economy in the design of macadam roads is greatly increased by utilizing local material, preferably uncrushed, to its fullest extent. We wish to emphasize this point (see design report, page 274). If the supply of local material is limited it should be used for as much of the road as possible and advantage should be taken of the different local supplies by changing the design to allow their use with short hauls.

Uniform designs which disregard limited amounts of local materials often raise the cost from $500 to $1000 per mile.

Conclusions.—In the design of a road, the amount of material required for the foundation courses can only be approximated. This is the only item in the preliminary estimate that can not be figured within definite limits. It can be closely estimated if careful data on the soils is obtained from local people and from the preliminary survey (see page 330) but a certain leeway must be given the constructing engineer so that he may vary the estimated depths to meet the construction conditions and build a consistent road. It will be noted that the depths recommended in this chapter are greater than those shown in most of the state sections throughout the book. This increase in depth is based on the observed action of traffic on the older macadam roads, which unless recapped with from 3″ to 6″ of additional stone are failing under heavy modern traffic. A macadam foundation is more suitable in northern climates for nine-tenths of the roads than a rigid pavement because it is flexible under frost action and with sufficient depth will hold the heaviest loads, but present practice in macadam design and maintenance is lagging behind the traffic requirements in the matter of depth while rigid pavement strength is well abreast of the times. The author has been amused at the recent comparisons of the effect of Army truck traffic across New York State on rigid and macadam roads. A considerable mileage of old thin macadam roads failed in spots but where a reasonable depth of macadam prevailed no foundation failures occurred. A blare of trumpets hailed the failure of the old cheap inadequately maintained macadams and great stress was laid on the fact that the rigid types held. This is mentioned to illustrate a phase of the present campaign for rigid types which the author considers unwarranted and dangerous from the standpoint of reasonable road design as it tends to discredit macadam construction. While we do not advocate macadam on Class I roads their use on Classes II, III and IV should be encouraged. (For traffic classification, see page 164.)

Macadam foundation failures are due to insufficient depth, insufficient consolidation during construction and poor grade

filler. The matter of filler is very important; coarse sand, pea gravel; or stone screenings are preferable and *earth or loam that softens when wet should never be allowed.* Filler should be a separate item separately paid for.

Macadam failures are due to the same cause as concrete failures of brick failures or any other failure—*ignorance and carelessness.*

CHAPTER VI

MACADAM TOP COURSES AND RIGID PAVEMENTS

The scientific selection of the most suitable pavement for a given road is the hardest problem of Highway Engineering. This selection is often simplified by local prejudice, commercial interest or clever propaganda but purely as a matter of academic interest we will discuss the matter from the standpoint of the millemium.

A reasonable decision depends on the requirements of the location, traffic, first cost, maintenance and renewal. Where the road is located in a village the elements of appearance, cleanliness, etc., have an important bearing. Where it is strictly a rural road looks have small effect and first cost usually governs. A large volume of extremely heavy load traffic makes a rigid type desirable and safe footing for team traffic limits the use of many pavements on steep grades. The relative economy of different pavements is theoretically expressed by the sum of the first cost and the capitalized cost of maintenance and renewal. The first can be readily estimated but the cost of maintenance and renewal can not be figured with any degree of accuracy for single special cases and even on large systems it can only be approximated on account of the uncertainty of future labor and material costs and the inadequate and spasmodic legislative finance programs for the upkeep of highways.

As stated in the introduction we believe that after the large decision has been made as to whether a rigid or flexible type is advisable, that the selection of special styles of construction within these classes has very little effect on the final cost of maintenance and renewal and that the problem can be confined to which of the types will utilize local materials to the best advantage and will be the cheapest in first cost, except as modified by footing on grades or appearance in villages and city streets which only applies to a limited mileage. The decision as to general type depends on the kind and volume of traffic. On any road the amount and class of traffic will fluctuate and roads that are designed for light travel will often fail under temporary heavy traffic which for some reason is diverted from its normal course. The first improved roads in any locality will for a time carry more than their share of the travel which is naturally reduced by the subsequent construction of adjacent improvements or may be increased by the linking up of isolated improvements into a continuous route of improved roads between large centers of population. It can be readily seen

that it is difficult to judge the amount of traffic a road will handle and that a short time traffic estimate is valueless as a basis for a definite conclusion. The design of the top course is usually based on a comparison of the action of different kinds of previously built roads that serve districts similar to that under consideration and this can be better determined by a study of the locality than by a localized traffic census. Roads on which high type macadams or rigid pavements are suitable may be divided into four general traffic classes.

Class I.—Main trunk roads between large cities along natural transportation routes which accommodate through truck freight traffic. Main radial roads from 5 to 20 miles out of cities of say 50,000 and upward and in the business section of villages which carry the concentrated farm and truck traffic of a large area and are subjected to continuous heavy load travel.

Class II.—Main through automobile pleasure routes at greater distances from the cities which have a large touring car traffic and medium heavy farm traffic and some heavy trucking.

Class III.—Secondary or feeder roads and cross roads having a medium heavy farm traffic and light auto travel.

Class IV.—Pleasure or scenic roads that carry a large number of pleasure autos but light street tire traffic.

Class I roads are better served by rigid pavements. Classes II, III and IV by flexible types.

Rigid pavements are economical on perhaps 10% of the mileage of improved roads that will be undertaken in the U. S. during this decade. They are destroyed by the action of the elements more than by traffic. They crack due to the settlement of new fills and frost heave; they shatter due to changes in temperature; they are harsh for horse traffic; they are comparatively difficult to repair and are prohibitive in first cost except for rich communities. They however handle heavy auto trucking more satisfactorily than macadam construction. They need comparatively little surface maintenance and for this reason traffic is inconvenienced less than on macadams; they last a longer period without reconstruction than macadams and traffic is therefore interrupted less; they bridge over small areas of weakness in the sub-grade, culvert, backfills, etc., better than macadams. There is no question but that they are desirable on Class I traffic roads. Under Class II traffic however from an economic point of view their selection is doubtful if macadam materials are available. Where they are used it is merely a tacit admission that the road authorities can not handle macadam maintenance and adopt the rigid type to tide over their terms of office. The flexible macadam type complies better with the usual conditions. It is generally cheaper in first cost, is not seriously damaged by settlement of new grading or frost heave; can be easily repaired; can be gradually strengthened by the addition of stone to meet practically any loading and when necessary can be recapped with a higher grade surface which rids it of the continuous maintenance drawback. Macadam surfaces

however require continuous maintenance and more frequent reconstruction and are the victims of a poor maintenance system. This last is the real reason for most of the dissatisfaction with macadam roads and results in the harsh verdict of the doggerel.

> "Who builds a road for fifty years that disappears in two,
> Then changes his identity so no one's left to sue.
> Who covers all the traveled way with a filthy oily smear,
> The bump providing rough on riding Highway Engineer."

This chapter describes the advantages and disadvantages of the various types. The preceding discussion and Table 22, page 190, indicate in a general way their economic limitations. The costs given are relative only and apply to New York conditions during 1910 to 1914. Labor \$0.175 to \$0.20 per hour. Teams \$4.50 to \$5.00 per day and cement approx. \$1.20 net. Most of the cost data given in Chapter XIV is for the same period. Maintenance methods are discussed in Chapter VII.

WATERBOUND MACADAM

Waterbound macadam is constructed of crushed fragments of suitable rock filled with rock dust and sprinkled and rolled until firm and hard. The cost varies from about \$3.50 per cubic yard where local materials are available to \$6.00 where the stone is imported and the haul is long. A fair average price for roads in Western New York would be \$4.30 per cubic yard or \$0.35 per square yard for a 3″ consolidated depth.

Depth of Course.—As the top stone is relatively more expensive than the bottom course a good design calls for the least thickness of top which can be successfully constructed and maintained. In 1901 the thickness used for top-course macadam in Massachusetts, New York, Connecticut, and New Jersey was 2″, and the size of the top course stone fragments ranged from ½″ to 1½″ in Massachusetts to 1″ to 2″ in New York. Experience demonstrated that with a course as thin as 2″, the larger stone fragments tended to "kick out" under traffic and that the top wore out by raveling rather than by the abrasive action of the teaming. For this reason the best practice at present calls for a 3″ depth of finished top course, using stone ranging in size from 1¼″ to 2¾″; this depth makes it possible for the large stone fragments to interlock more firmly than in a 2″ course. Where a pit run gravel bottom course is used a 4″ depth of top is desirable on Class II roads.

Crowns.—The crowns used on plain macadam range from ½″ to 1′, to ¾″ to 1′. Mr. Charles Mills, Chief Engineer of the Massachusetts Highway Commission reports the following loss of crown on State roads in Massachusetts and concludes that an original crown of ¾″ to 1′ is advisable on single track roads and ½″ to 1′ on double track roads. New York practice favors ⅝″ to 1′, on 10′ to 14′ width of metaling and ½″ to 1′ on 16′ to 20′ pavement widths.

TABLE 21B.—TESTS MADE IN DECEMBER, 1901

Date of Original Construction	Number of Tests	Original Crown (Inches per Foot)	Present Crown (Inches per Foot)
1895	7	0.694	0.500
1896	9	0.583	0.514
1897	12	0.645	0.500
1898	7	0.625	0.500
1899	2	0.688	0.625

From the Massachusetts Highway Report for 1901.

Maximum Grades.—Waterbound macadam gives a good footing for horses on the steepest grades that are ever constructed; the limit of grade for this construction is determined by the cost of maintenance; on steep grades macadam washes badly and the cost of maintenance is high. Good practice limits its use to grades of 5% or under, although it has been used and maintained successfully on grades as high as 12%.

Advantages and Disadvantages.—Waterbound macadam does not require particularly rigid inspection during construction and can be built under almost any weather conditions except freezing. By its method of construction the voids between the large stone fragments are completely filled with solid material and there is no tendency to squeeze or creep as in some of the asphaltic macadams. If carefully built it maintains its longitudinal and transverse shape and is an easy riding road for both team and motor traffic.

Plain waterbound roads generally loosen up during the spring thaw and if subjected to much traffic at this time are liable to ravel. This trouble is not experienced with the bituminous macadams. Under heavy automobile traffic a plain waterbound macadam is not satisfactory as the machines remove the fine dust particles between the larger stones, leaving a rough surface which "kicks out" under team traffic. For this reason waterbound roads which are receiving much motor traffic are generally being treated with some kind of a dust layer or a bituminous protecting coat, that will better resist the wear of automobile travel.

Waterbound Roads Treated with Dust Layers or Protected by Flush Coats.—If waterbound macadam is kept moist by sprinkling with water, rapid disintegration under light machine traffic, traveling at medium speeds is prevented. For light traffic, city or village streets, this is feasible, but the cost of sprinkling long stretches of country roads is prohibitive, and where the speed is high, as usually occurs on the main improved country roads, sprinkling alone will not satisfactorily protect a plain macadam.

The application of calcium chloride[1] to a road surface keeps the dust down for a longer period than sprinkling with water, as this salt

[1] We are indebted to Mr. Frank Bristow, Superintendent of Repairs, New York State Department of Highways, for much of the data on calcium, chloride, glutrin and cold oiling.

has the property of absorbing moisture from the atmosphere and condensing it on the road surface; on side roads two applications a season have kept the surface in good condition. The salt is applied with an ordinary agricultural drill, using about 1½ pounds per square yard for the first application and less for the succeeding applications. In Western New York the cost of the first application 12′ wide has been approximately $100 per mile. Complaints have been made that the application of too much calcium chloride has caused soreness to horses' feet, but using the quantities given above, no trouble has been experienced, to the writer's knowledge.

The application of calcium chloride does not build up the road or form a wearing cushion that protects the stone; it merely prevents the fine surface dust from being blown away or removed by the machines.

Glutrin.—Glutrin is a trade name for the liquid which is run out of sulphide tanks in the manufacture of pulp; it is distilled and the acids neutralized. It resembles molasses in color and consistency, is soluble in water, and is applied by sprinkling the surface of the road with one part glutrin dissolved in one or more parts of water, using from 0.3 to 0.5 gallons of the glutrin mixture per square yard treated. The road surface need not be swept if the dust is not more than ¼″ deep. It hardens the surface to a certain extent, and, apparently, prevents raveling if applied twice during a season on roads receiving a moderately heavy traffic. According to Hubbard an addition of 5% to 15% of semiasphaltic oil to the glutrin prolongs its efficiency, but such an addition tends to produce an oily mud in continued wet weather; glutrin alone does not produce this objectionable condition. Glutrin has been laid in New York State under an agreement with the Robeson Process Company of Ausable Forks, at a cost of $0.04½ to $0.06½ per square yard of surface actually treated.

Cold Oiling.—Macadam surfaces treated with light refined tar or asphaltic oil give a nearly ideal surface after the slippery, sticky condition has disappeared.

The road to be treated is swept clean of dust and the oil is applied by pressure sprinklers, using from 0.1 to 0.3 gallons per square yard. The surface may be dry or slightly moist when the oil is applied. It is then covered with a good quality of pea gravel, stone or slag screenings or a sharp, coarse sand. In Western New York the cost has ranged from $0.02 to $0.04 per square yard, including sweeping, materials (oil and cover) and the labor of placing.

To derive a season's benefit from the application of light oil or tar, the surface of the macadam must by thoroughly impregnated with the bitumen. Some of the lighter oils will evaporate. The cover will absorb some more. To get the greatest degree of saturation of road surface therefore, with a resultant freedom from dust and disintegration, the cover should be the smallest amount of stone that will smooth out or eradicate that "toothy" or mosaic" effect of small shallow voids between the firmly locked top stone (see page 202).

On medium traffic roads (Class II) one application a season is sufficient and on light traffic roads (Class III) one application will sometimes last for two seasons.

Hot Tar and Asphaltic Residuum Flush Coats.—Bituminous flush coats are applied by sweeping the macadam carefully to remove all surface dirt as well as the stone or sand filler to a depth of about ½″ below the top of the larger stone fragments. On this rough, clean, dry surface a heavy refined tar or a bituminous residuum of the binder grade is spread hot, using from 0.2 to 0.8 gallons per square yard. The binder is applied at temperatures ranging from 250° to 400°F., and is spread either by hand sprinkling pots or is sprayed on by specially devised pressure sprinklers. It is then covered with a layer of clean No. 2 stone (¾″) or dustless screenings and thoroughly rolled. A well constructed surface of this kind resembles asphalt. It protects the macadam from raveling, is waterproof, forms a surface which takes the wear of the traffic from the large stone fragments, and gives a pleasing appearance. However, it cannot be laid in wet or cold weather; like asphalt, it is slippery and will not give satisfactory footing for horses on grades over 4%, and, unless laid evenly, will develop short, sharp waves or humps, which are very disagreeable for fast-moving automobile traffic. Some engineers advance the argument that by successive applications of such a flush coat a road can be maintained indefinitely without recapping, but as far as the writer has been able to observe, the roads become so humpy from continued treatment of this kind that recapping will be necessary to even up the surface on the score of comfort alone.

The use of hot tar application on a concrete road will be discussed on page 178. For use on an existing macadam road as repair, the authors believe that there is just one condition where a hot application should be specified; where an old road has begun to disintegrate unexpectedly, has passed the stage where cold oiling would rejuvenate it and funds are not available in the current year for resurfacing, then the hot oil or tar treatment may be used as a stop-gap to save it from complete disintegration for another year.

The cost of flush coats exclusive of covering ranges from $0.12 to $0.16 per gallon, or about $0.09 per square yard. If applied to a macadam road during construction the cost of the plain macadam is increased approximately $0.10 per square yard, making $0.45 per square yard a fair comparative figure for flush coat and water-bound macadam construction.

The crown ordinarily used on flush coat roads is ½″ to 1′.

All bituminous binders have the following practical disadvantages whether applied as surface coats or as binders in bituminous macadams. The composition of residuum products is so complex and so easily varied that, to get uniform results, each shipment must be sampled and analyzed to insure certain required properties. In heating, care must be taken not to char the binder, as this destroys its life and effectiveness. They can not be applied in wet or cold weather, which reduces the length of the construction season, and unless evenly spread a rough, humpy road results.

Bituminous Macadam.—Bituminous macadams are constructed in two ways, by the penetration method and by the mixing method.

Penetration Method.—Most of the bituminous roads in New York State have been built by this method.

The larger stone fragments, ranging in size from 1″ to 2″ to 2½″, depending on the depth of the course, are spread and rolled; a heavy grade of refined tar, residuum bituminous material, or fluxed natural asphalt, is then poured hot, either by hand or machines (see footnote) into the voids of the stone so that the stone fragments are covered with a thin coat of bituminous material; No. 2 stone, or dustless screenings are spread over the surface and broomed and rolled until the voids are filled; if a flush coat is to be used the excess filler is broomed off and the surface applied in the same manner as described for plain macadam. Where the flush coat is not applied, a wearing coat of clean screenings is spread over the surface.

The amount of bituminous material used as binder varies from 1.25 gallons to 1.75 gallons per square yard, depending on the depth of the course. The amount used for flush coats ranges from 0.2 to 0.5 gallons per square yard.

The cost of one-coat 2″ bituminous top, using 1.25 gallons per square yard, will range from $0.35 to $0.45 and a 3″ one-coat top, using 1.75 gallons per square yard from $0.50 to $0.60 a square yard. The flush coat using 0.4 gallons per square yard will add about $0.06 to the above costs. For the purpose of comparison with the macadam a fair set of prices is

2″	Bituminous	top,	one coat of bitumen........	$0.40 per sq. yd.
2″	"	"	flush coat..................	0.45 " " "
3″	"	"	one coat of bitumen........	0.55 " " "
3″	"	"	flush coat..................	0.60 " " "

Depth of Top Courses for Bituminous Macadams.—In 1910 New York State adopted a depth of 2″ using 1.25 gallons as binder and 0.5 gallon as flush coat per square yard.

In 1911 a 3″ depth was used with 1.25 gallons per square yard as binder and 0.4 gallon as flush coat.

In 1915 a 3″ depth was used with 1.75 gallons as binder and 0.5 gallon as flush coat.

A 2″ bituminous top will not fail by raveling, the defect mentioned for a 2″ waterbound macadam course, but it has certain constructional difficulties. To construct a 2″ course no stone should be over 2″ in its largest dimension. Because of the tendency to

The author has had better success with hand pouring for the first coat than with machine work. For flush coats, however, a pressure machine is absolutely necessary. If bitumen is poured by hand it must be poured across the road (never along the road) as this method of work largely eliminates humps formed by overlap. It is much easier to control the hand spread than the machine spread as to amounts and the stone spread is not disturbed or rutted up during the pouring. While the machine spread is uniform this is in itself a drawback on the first coat as the rough stone sizing is never uniform and a hand spread can be varied to conform to the non-uniformity of the stone sizing.

crack under concentrated wheel loads, none of the stone forming the main body of the course should be less than one inch in size. These limits of size are so narrow that difficulty has been experienced in procuring sufficient stone for top when crushing local material, and even when the stone is obtained from a commercial plant the same difficulty is often encountered. Also in spreading such a depth with stone ranging in size from 1" to 2", there will be places where the metaling is only one stone deep and the fragments do not fit as closely together nor have the same chance to interlock as in a deeper course. The spaces between these stones are filled with No. 2 (¾") size, which wears more rapidly under traffic than the larger pieces and the road tends to become rougher than would occur if the 1½" stone fitted closer together.* This last argument does not apply to flush coat roads.

The argument is often made that a 3" top will last one and one-half times as long as a 2" top because it has one and one-half times as much material, but the life of a top course rarely depends on its total thickness, as it will become so badly out of shape before the general elevation has worn down an inch that it will need recapping.

In attempting to meet these difficulties, 2½" and 3" courses have been built; as far as the author has been able to judge, the 2½" depth remedies the defects, and can be used where imported commercial crushed stone is available, but where the stone is crushed locally a 3" depth is better with a slightly greater range in top stone size.

When pouring bitumen in the penetration method, a pocket of fine stone, dirt, etc., will sometimes hold the binder near the top in too great quantities; during hot weather the bitumen swells and, as the voids are full in these spots, it rises to the surface and forms a hump or wave. This trouble is not so frequent on either 2½" or 3" courses as on the 2" depth.

The writer's present opinion is that while a 2½" depth, using about 1.4 gallons bitumen per square yard in one coat, will give satisfaction that a 3" depth using 1.7 gallons in one pour is better practice on a macadam bottom. On a pit run gravel bottom 3½" with 1.8 gallons of bitumen is desirable. Where bituminous macadam is used to resurface an old worn out concrete road on steep grades 3" to 3½" is the best depth.

Crowns.—The crowns used on bituminous macadams range from ¼" to 1' to ¾" to 1'; ½" to 1' is generally used and is apparently satisfactory.

Footing.—A single coat road affords good footing on any grade that will be adopted as suitable for heavy hauling; such a top course will not wash, which makes it easy to maintain on hills.

Advantages and Disadvantages.—Bituminous macadam without a flush coat provides good footing for horses; it will not ravel, is easy to repair for small depressions and ruts, is comparatively dustless and keeps its longitudinal and transverse shape well, making a comfortable riding road for fast travel. On the other hand, it will probably wear more rapidly than the flush coat

construction as the traffic comes directly on the stone; it is subject to the practical disadvantages of construction of all roads where bituminous materials are used; it is not waterproof when first constructed; this last defect, however, is remedied by the traffic which grinds up the surface wearing coat and forces it into the voids. As a matter of fact, the combined action of traffic and weather puddles the road, and after about six weeks' use we can say that the road has a bituminous bond and a water-puddle finish.

Flush coat bituminous macadams are more dustless than the single coat, are more nearly waterproof when first built, look smoother at first, and will probably cost less to maintain. However, they do not give as good a footing as the single cost and are liable to develop waves and humps disagreeable to fast traffic.

If a flush coat is used there seems to be no advantages in a bituminous binder, as the flush coat alone prevents raveling, and, if such is the case, the binder used throughout the depth of the course is a waste of money; a waterbound bituminous flush coat course might better be used. In choosing between a flush coat construction or a single coat bituminous macadam, the author believes that a single cost bituminous macadam is the better design; although it will probably cost more to maintain, the increased safety and comfort to the traveling public is worth the expenditure. Unusual care in construction is required (see Chapter XV).

Gravel Bituminous Top.—A gravel bituminous bound top is rarely satisfactory as it lacks the interlocking action of broken stone which increases the stability of construction. The use of this type is not advised.

Mixing Method—Open Mix. Type I.—The stone and bitumen are mixed hot in specially designed machine mixers. The mixture is then spread in the same way as sheet asphalt. A flush coat can be used if desired. The 1915 New York State specifications call for No. 2 stone (5/8" to 1 1/4"); when finished thickness is to be 2" or less and a mixture of No. 2 and No. 3 stone (1 1/4" to 2 1/4"); when finished top course is greater than 2", the stone to be proportioned as directed by the engineer. Approximately 18 gallons of bituminous material to each cubic yard of loose stone.

In this "open" mix, it is unavoidable that pockets of mixed top material will be placed which have a greater percentage of voids than the average. Whether or not a seal coat is used, these pockets will wear more rapidly than the surrounding pavement. In a similar manner, variations in the size of the stone will cause uneven wear. Both conditions tend to produce a humpy pavement after some use, but generally a smoother riding road is produced than is attained with carelessly built penetration roads.

Mixing Method—"Tight Mix" or "Topeka." Type II.—The stone, sand and bitumen are mixed hot in specially designed machine mixers. The mixture is then spread in the same way as sheet asphalt. The thickness varies according to the foundation. It is generally a consolidated depth of 2" on a concrete foundation and 2 1/2" on a firm macadam foundation. The various sizes of the

mineral aggregate and the percentages of each are specified within certain limits varying slightly to meet gradations peculiar to the material available (see specifications, page 781).

Because of the fine aggregate used in work of this type, there is not sufficient stability to withstand a mixed traffic and the surface ultimately forms in disagreeable waves.

Attempts have been made to prevent this waving by using a high penetration asphaltic cement which will permit the pavement to iron itself out. However, if a heavy slow-moving traffic be carried on this type of road, the surface will rut.

Apparently, the best results in mixed bituminous macadam have been secured when the coarse aggregate was used—stone between three-quarter inch and one and one-half inches in size, which were filled with a matrix of fine material of sand and bituminous material. Such pavements have sufficient "body" to materially decrease the "creeping" under use and take a more even wear than the open mixed type. Where used to recap an old concrete or macadam road an open binder coat is desirable to even up the old surface and allow a uniform depth of surface mix.

The prices for this type of top course run from

$$\frac{\text{Type I, \$0.615}}{\text{Type II, \$0.60}} \text{ to } \frac{\$1.105}{\$1.25} \text{ per square yard}$$

Natural Rock Asphalts.—Sandstones and limestones containing a certain percentage of bitumen are known as rock asphalts. The most common source of supply for the Eastern States is Kentucky, and the product is known as "Kentucky Rock Asphalt." It is a sandstone containing about 7% to 10% of maltha. It is pulverized at the mine and is shipped and applied cold in the following manner: 2" to 2½" of stone, ranging in size from ¾" to 1½", are spread and rolled slightly. The rock asphalt is run through a shredding machine and spread over the stone, using approximately 40 lb. per square yard. The whole mass is the thoroughly rolled, preferably with a 6- or 8-ton tandem roller; 40 lb. per square yard of pure rock asphalt is then spread as a wearing coat and well rolled; the rolling is continued intermittently for a number of days after the traffic is turned on the road. The cost of such a course has been about $0.70 per square yard in Western New York.

The crown ordinarily used is ½" to 1'.

Advantages and Disadvantages.—The road is pleasing in appearance, is not as slippery as sheet asphalt, and will not ravel under motor traffic. However, it is hard to construct in cold weather, is not uniform, and will ravel in spots. It has defects in common with sheet asphalt of showing wear by developing short humps and hollows disagreeable to fast traffic. The steepest grade on which it can be used advantageously is about 5%, as it becomes slippery in cold weather, and in warm weather it sometimes softens enough to make hard pulling for heavy loads.

Amiesite.—Amiesite, a patented material made of crushed stone coated with asphaltic cement, has been used on many miles of

road with good results. It is shipped cold in a friable and granulated state, spread on either macadam or concrete base and well rolled. Amiesite screenings are then spread and rolled, forming the surface. This construction costs about $1.00 per square yard, 3″ thick. It resembles asphalt in appearance and has the advantages and disadvantages of all roads of this class. It is particularly adapted for small jobs where it would not pay to set up an asphalt plant or where suitable asphalt materials are not locally available.

For further information, see Chapter on "Cost Data and Specifications."

Other Surfaces of a Bituminous Nature.—There are any number of patented pavements that can be classed under this head to which we can not give space.

Sheet Asphalt and Warren Brothers' Bitulithic are used in unusual cases, but constitute such a small percentage of the mileage that for information concerning them we refer the readers to books by Richardson, Hubbard, Tillotson, etc. We include some notes on inspection of construction, page 677.

BRICK PAVEMENT

The ordinary brick pavement construction is probably familiar to most readers. On a concrete foundation 5″ to 7″ in thickness a sand cushion varying in depth from 1″ to 2″ is spread and the paving brick are laid on this sand bed so as to break joints; the brick are well rolled and the joints are filled with sand, cement grout or paving pitch. Longitudinal expansion joints of bituminous material are provided next to the curb or edging; transverse expansion joints spaced 30′ to 50′ apart are used by some designers. The latest practice tends to make the cushion as thin as possible 1″ to 1½″, acting merely as an evener of the concrete surface. It is also rare to find any material but cement grout used for filler though this tendency is not necessarily an improvement. The use of transverse expansion joints is being relegated to the background but this also is open to argument. Premolded asphaltic strips form the best kind of expansion joints where they are needed. In the last few years the former theory that the 1½″ sand cushion prevented crushing of the brick and gave the amount of resiliency necessary to a pavement of this type has been disputed and apparently successfully so, by the increased use of the cement sand cushion. Upon the finished concrete base a bed of dry cement and sand uniformly mixed in the proportion of one part cement to four parts sand is spread not over 1″ deep. This cushion is shaped by striking with a template and finished by rolling with a hand roller weighing about 300 lb. and restruck or luted. After the brick are laid theron, culled and rolled, the pavement is thoroughly sprinkled to set up the cement sand bed. The use of this kind of bed undoubtedly overcomes the loosening of bricks near cracks or expansion joints and prevents shifting of the sand cushion which sometimes occurred with pure sand and resulted in depressed areas. It is possible that the use of this kind of a cushion in con-

junction with bituminous joint filler will help to overcome the serious fault of surface cracks which develop under frost action.

In 1915 several experimental brick pavements were constructed where the mortar cushion and brick were laid upon concrete which was still plastic. The concrete foundation was shaped by a template and the brick laid, inspected and rolled before the cement had taken its initial set. This is immediately followed by grouting. It is too early to say whether or not this so-called "monolithic" construction will be successful. The expense and difficulty of manipulation are increased and it is doubtful if any material advantages are attained.

Brick pavement construction is essentially rigid, intended to withstand heavy traffic. The cost, including foundation and surfacing, ranges from about \$1.60 to \$3.00 per square yard, the average price in Western New York being about \$2.00.

Brick pavements on heavy traffic roads have been extensively used in Ohio and New York. Macadam foundations for brick surfacing have not proved satisfactory in the Northern States, as the surface is too rigid and cracks under the heaving action of

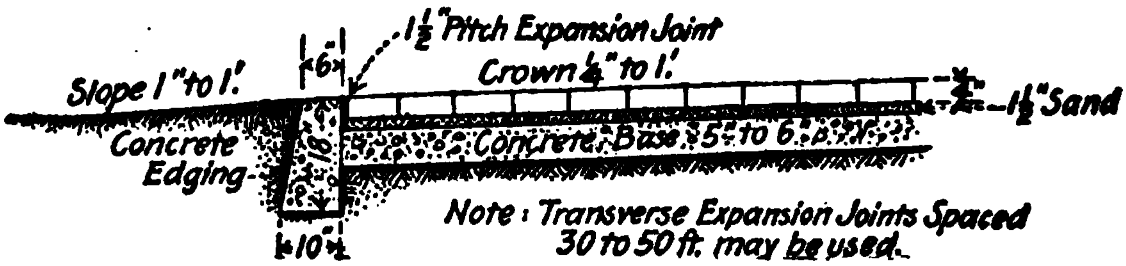


FIG. 36.—Brick pavement, flush edging.

the frost. Even on a concrete foundation longitudinal cracks often develop from this same action. It is more difficult to prevent this on country roads than in cities where the sewers keep the earth sub-grade comparatively dry, and the necessity for a center drain under the concrete base is being recognized by many designers. Some engineers believe that the 1 to 1 cement grout in general use is too strong, and that if a weaker grout or a sand filler were adopted in its place the heaving frost action would merely separate the bricks slightly instead of breaking them and that as the road settled they would fall back into close contact. This is an attempt to make a theoretically rigid construction flexible and seems to be striving to adapt the construction to conditions for which it is not fitted.

Longitudinal Cracks.—These cracks have been carefully studied, as they seem to be the most discouraging feature of brick pavement construction on country roads.

Mr. Wm. C. Perkins, Chief Engineer of the Dunn Wire Cut Lug Brick Company, states from a careful examination of a large mileage of brick roads built under his supervision, that longitudinal cracks have always occurred within 2′ or 3′ of the center of the road; that the cracks extend down through the concrete base and that less difficulty is experienced in preventing them as the crown of the pavement is reduced. From these observations he has been

led to experiment with a concrete base having a perfectly flat bottom, as shown in Figure 36A, crowning the road by making the concrete thicker in the middle than on the edges. The claim is made that this style of construction is helping to prevent such cracks.

Transverse Expansion Joints.—The use of transverse expansion joints has not been successful locally. Difficulty has been experienced with the brick loosening at these joints, and whenever a temperature heave has occurred it has appeared at the joint. Their use has been abandoned for rural roads in Western New York. This does not occur with a cement sand bed but excessive wear does occur at such a joint.

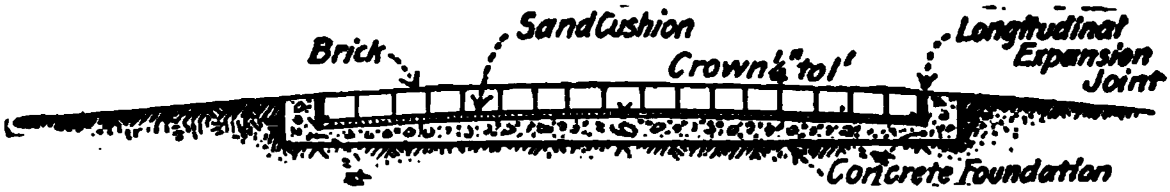


FIG. 36A.

CROWNS

The crowns in use on brick pavements range from ¼" to 1 to ⅜" to 1'. For the methods of figuring ordinates for parabolic crowns see page 551.

Brick pavement does not give a good foothold for horses on grades above 5% unless some special form of brick is used. For steep grades, on heavy traffic roads, it is better practice to use some form of stone block.

Stone block pavement, including concrete foundation, costs from $2.70 to $3.30 per square yard. It is suitable for the steepest grades that are constructed and is the most durable pavement that can be used.

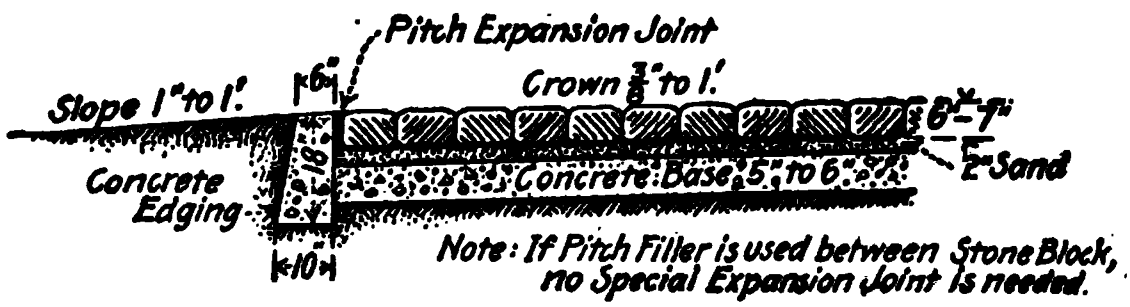


FIG. 37.—Stone block pavement, flush edging.

Where stone blocks are used on hills it is better practice to use second quality blocks; these blocks are identical with the first quality blocks as to material but are not dressed as carefully and cost about fifty cents per square yard less; their rougher surfaces and wider joints afford better footing. For the difference in size and joints see specifications, Medina Block, page 736.

The first cost of brick pavement for country roads restricts its use to roads where it can be conclusively proved that macadam will not be suitable. It is a reasonable design for Class I traffic in villages.

ASPHALT BLOCK

The asphalt block pavement laid in New York has been very satisfactory. The proportion of ingredients is about 70% crushed rock, usually trap, which has passed a 1/4" ring, about 20% limestone dust to act as filler and approximately 10% of asphaltic cement, molded under a pressure of 2 tons per square inch of block having a 2" depth. This produces a dense asphalt much superior to the ordinary sheet.

The asphalt used is Trinidad. This is refined and fluxed so that the resulting A. C. may be varied as to adhesiveness, penetration, etc., to meet varying conditions peculiar to different localities.

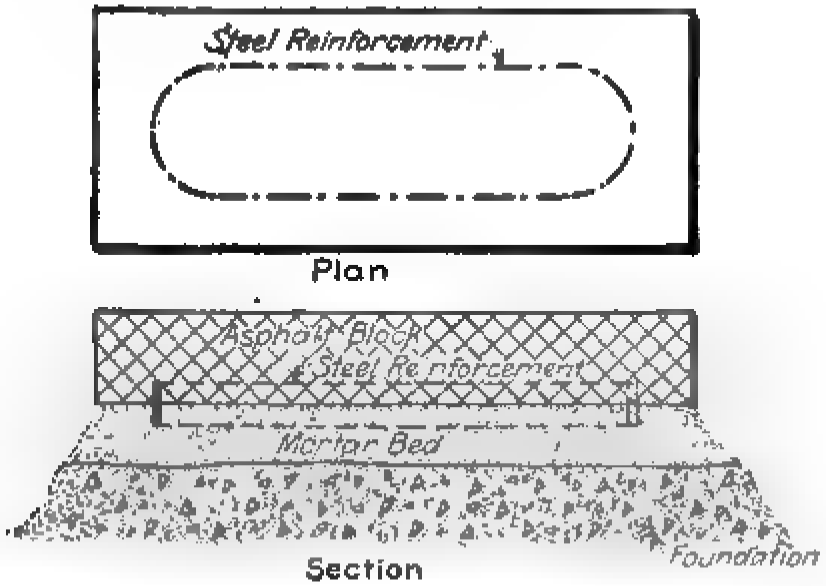


FIG. 38.

The penetration is made high enough to give a certain amount of pliancy to the block, to avoid crumbling at the edges and to make the joints self-healing.

The use of blocks containing steel anchors, laid across the road, approximately 15 ft. apart, has eliminated any movement of the block under traffic. These blocks are placed at more frequent intervals on curves. Block pavements have been laid using a longitudinal row of these anchor blocks in place of edging. The results appear satisfactory.

After the base is prepared a mixture of 1 to 4 Portland cement mortar is spread 1/2 in. thick. This mortar bed is carefully screened and the block laid thereon, joints being broken at least 4 in.

An interesting comparison with brick occurs in the "pinning in" at curbs. Instead of bats being broken by hand, a large mechanical shear is used. Each fractional block is measured and cut to fit exactly.

ASPHALT BLOCK DATA

Highway No.	County	Mileage	Bottom per Sq. Yd.	Top per Sq. Yd.	Per Mile 16′–26′
5357	Westchester	0.95	$0.61	$1.49	$26,593
5375	"	1.34	Old Mac	1.69	18,114
5388	Rockland	2.16	" "	1.70	[1]27,025
			0.59	1.70	[1]32,525
1153	Niagara	0.97	0.60	1.37	[1]31,800
5482	Westchester	1.16	0.66	1.50	29,270
1167	"	1.28	0.61	1.38	24,245
1053	"	1.45	Old Mac	1.60	21,205
5528	Warren	0.61	0.59	1.60	35,990
5356	Westchester	0.53	Old Mac	1.63	[1]26,960
5361	"	0.68	0.61	1.44	[1]23,512
5362	"	0.25	0.67	1.37	25,569
5364-A	"	0.31	0.47	1.47	23,166
5373	"	2.85	0.58	1.52	
			Av. 0.599	Av. 1.533	

[1] Cost from preliminary estimate.
All costs not marked with [1] from bid prices.

After being laid, the pavement is given a light coat of sharp sand which is broomed into the joints. Traffic is permitted in four or five days.

Advantages.—The pavement shows a smooth, uniform surface, dustless and practically noiseless. Its life has yet to be determined. Pavements that have been down ten or fifteen years are still in good shape. Within a reasonable freight radius from the point of manufacture, it can be laid for approximately the cost of brick.

Disadvantages.—A mist or light rain makes the pavement very slippery. It should not be used on grades over 4%.

CONCRETE PAVEMENTS

Introductory

Inasmuch as there is some difference of opinion as to the value of this type each author has written his interpretation of the available facts.

Concrete Pavements

BY W. G. HARGER

Many miles of these roads have been constructed in the last few years.

The construction has varied from poor 1 to 6 pit run gravel concrete to first-class 1 : 1½ : 3 stone concrete 6″ to 9″ thick.

There is enough data to conclude that cheap concrete is a failure. An effort was made to protect the surface of such a mix with a thin bituminous surface coat of asphaltic oils or tars. These coats have not been successful as they peel off and produce an unsightly, rough riding and a high maintenance cost road.

The type of concrete road now being built and which has many enthusiastic supporters is a first-class 1 : 1½ : 3 stone or screened gravel concrete which takes the traffic directly on its surface. The concrete is carefully manipulated (see specifications, page 785). The ordinary section used is shown in Figure 39. Expansion joints of premolded asphalt or patented steel plates with tarred paper filler are provided at intervals of approximately 30 ft.[1] The cost of this pavement has been from $1.10 to $1.80 per square yard. They have the advantages and disadvantages of all rigid types of construction. They should not be used on grades over 5%.

Pavements of this class have been built on roads having light, medium and heavy traffic and are advocated by Cement Manufacturers as an economical road under all classes of traffic. The author believes that while this type has its place that a great mileage is being constructed which from an engineering viewpoint is not justified. The roads have not been down long enough to obtain

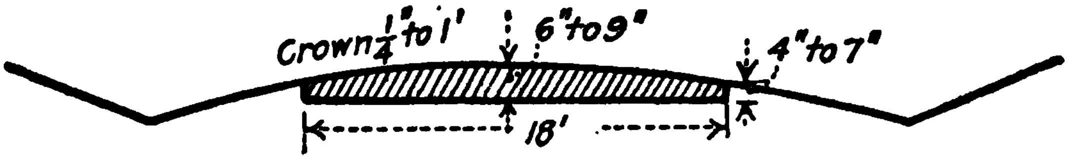


FIG. 39.

reliable data as to their length of life before resurfacing. Considering in a general way, however, what we know of the material and the action of the weather and traffic on rigid types of pavement, an allowance of 10 to 15 years would appear liberal. When they arrive at the point when they need resurfacing a large expense is involved. It has been demonstrated that cheap thin bituminous coats have not been successful; it is not possible to successfully resurface with a thin layer of concrete which means that probably asphaltic concrete, asphalt block, brick or some other form of block or cube pavement will be used at a cost of from $9,000 to $16,000 per mile. The fact that resurfacing when it occurs requires such a large expenditure eliminates this type from use on any but the more important roads which constitute a small percentage of the mileage of any large system.

With the data at hand the indications are that this type is a good design for Class I roads outside of villages and possibly for the heavier Class II roads under special conditions.

Under Class I traffic an average depth of 8″ of concrete is recommended and a minimum width of 18′ on account of the difficulty of shoulder maintenance (see Plate 9, page 60).

[1] The author personally believes that better results will be obtained by eliminating these joints altogether. The artificial joints are sources of weakness in that they tend to localize the wear. Apparently less wear occurs at a natural crack and it is certain that a smoother riding road is obtained.

If used on Class II roads a depth of 7" will probably be sufficient but no reduction in width is allowable. The fact that more width is desirable for all rigid pavements than for macadams on Class II traffic is an added reason for the use of macadams under these conditions (see Chapter on "Sections," page 42).

Under climatic conditions free from frost an average depth of 6" is sufficient and under ideal soil conditions 4" to 5" have been built (see "California Standards," page 50).

First-class concrete is showing up better than anticipated under Class I traffic but the desirable depths, widths and necessary refinements of construction to insure success are increasing the cost per square yard and eliminate it as a competition for macadam on Classes II and III roads where macadam materials are available.

CONCRETE BITUMINOUS ROADS

By E. A. Bonney

Some four or five years ago, a tremendous wave of publicity swept concrete roads into the limelight. The construction at that time consisted of a second-class concrete base with a skin coat from ¼" to ¾" in depth, composed of screenings, mixed with hot oil or tar, and sometimes a combination of the two. The base was laid without joints and gravel or any kind of stone was used for aggregate.

Under this type at least a dozen patented pavements were developed practically none of which have to any degree borne out the extravagant claims made at that time.

The bituminous skin coat has not been satisfactory. It is subject to all the disadvantages of other bituminous macadams and with few exceptions has not adhered to the concrete for any length of time.

There is a road known as the Bedford-Goldens Bridge State Highway in Westchester County, on which 2.67 miles of concrete base has been laid when the original contract was canceled. The unfinished portion was covered with an experimental skin-coat treatment which today (1916) is as sound and intact as when laid. Work was finished in the early summer of 1915. The road was subjected to the enormous automobile traffic peculiar to Westchester County all season. A brief description follows:

The concrete was cleaned, all dust, dirt or caked material removed. It was then coated with a cold application of low carbon tar, very light grade, almost a creosote. This was spread about 1/10 gallon per square yard and allowed to dry for two hours. About one-third of a gallon per square yard of Bit. Mat. "T" low carbon was then applied hot and covered with approximately 37 lb. binder of No. 2 stone per square yard. A second coat of ⅓ gallon per square yard was then applied and covered with about 32 lb. per square yard of No. 1 stone (screenings).

This treatment so far looks extremely well and has not broken away from the concrete. It is still too early to classify as a success.

The cost of the top course only was 17½c. per square yard. Base cost 68c. making total of 85c.

CONCRETE PAVEMENTS

By E. A. Bonney

1 : 1½ : 3 Mix

Concrete pavements are showing as each season passes by, that they are worthy of much more consideration than has been given them up to the present time. For roads subjected to heavily loaded and slow moving vehicular traffic or for roads so located or traveled that any type of macadam road would be subjected to costly maintenance, the concrete pavement has come to stay. The wear seems to be inappreciable and because of the flat crown, traffic is spread over the entire width of metal.

Great care must be exercised in the selection of aggregates. Many sands that are considered good enough for ordinary concrete work will not give satisfactory results in concrete pavement. Stone or gravel should be limited to those showing a high coefficient of wear.

Considerable attention should be paid to the percentage of voids in the sand and stone. Experiments should be made to determine approximately the mixture giving the lowest percentage of voids. The authors do not believe in the blind adoption of a specified mix. It is often essential that the mix be varied to correspond to the gradation of available sand and voids in coarse aggregate.

Several containers of uniform volume and a pair of scales are all the apparatus necessary to show whether or not the specified mix is the best mixture for the aggregates available.

The approximate percentage of voids, may be found by water. By making up several concrete cubes or cylinders of the same volume, beginning with the specified mix and varying the others as indicated by the percentage of voids, the heaviest product will indicate the proper mixture.

Any data given herewith is based upon a one-course road. The authors are not personally familiar with two-course roads.

Bulletin No. 249 of the Office of Public Roads, U. S. Department of Agriculture, cites the advantages and disadvantages of concrete highways as follows:

"**Advantages.**—1. As far as can be judged, they are durable under ordinary suburban and rural traffic conditions. While it is true that there are no very old concrete pavements in existence, the present condition of many of those which have undergone several years' service would seem to warrant the above statement.

"2. They present a smooth, even surface, which offers very little resistance to traffic. In the past the surface of concrete pavements have sometimes been roughened in order to insure a good foothold for horses. This practice has now been abandoned, except on very steep grades, because it tends greatly to accelerate deterioration of the pavement, and because the smooth surface has been found to afford a fairly satisfactory foothold under all ordinary conditions.

"3. They produce practically no dust and may be easily cleaned.

"4. They can be maintained at comparatively small cost until renewals become necessary.

"5. They may be made to serve as an excellent base for some other type of surface when resurfacing becomes desirable.

"6. They present a pleasing appearance."

"The Disadvantages.—1. They are somewhat noisy under horse traffic.

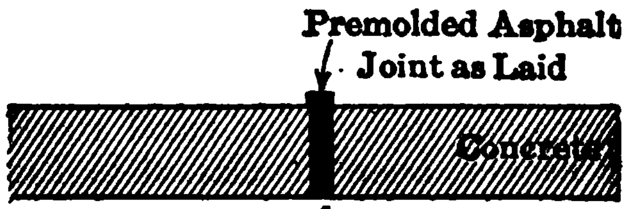
"2. There is no method of constructing necessary joints in the pavements which will entirely prevent excessive wear in their vicinity. Furthermore, joints do not altogether eliminate cracking and wherever a crack develops it must be given frequent attention in order to prevent rapid deterioration of the pavement.

"3. They can not be readily and effectively repaired as many other types of pavements."

This summation of concrete roads in general seems eminently fair. We believe, however, that to the disadvantages should be added the inevitable rut which appears between the edge of the concrete and the earth shoulder. These ruts are dangerous to fast-moving traffic and require constant maintenance for their elimination unless the shoulders are armored with crushed stone or gravel for 2 ft. or more from the concrete.

The question of reinforcement and joints are still the subjects of much discussion among engineers.

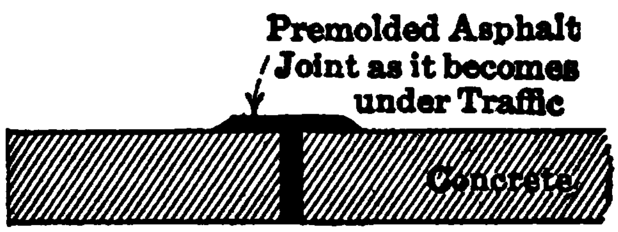
The item of reinforcement largely increases the cost of the roads and it is yet too early to say that the added expense is justified.



A

The joint problem affords an unlimited field for a variance of opinions. Few engineers are satisfied with any of the existing armored joints, patented or otherwise.

The author believes that experience to date has divided the problem of joints into two fields: *i.e.*, on roads under continued



B

maintenance a bituminous joint will prove satisfactory and is renewable at small cost; on roads which receive spasmodic maintenance or none at all, some sort of steel joint should be used.

On New York State work where maintenance is continuous the most satisfactory joint to date is of premolded asphalt, which is so placed that it projects from ⅜″ to ½″ above the surface of the concrete; as shown above (*A*).

A combination of hot weather and traffic spreads the asphalt out, leaving a bituminous mat over the joint.

For concrete roads not under maintenance, the better joints are being made of soft steel tempered to the same relative hardness as the concrete. A hard steel joint simply transfers the point of wear from the joint-edge proper to the concrete back of the joint.

The proper length of concrete slabs between joints is another subject of speculation. Many roads are now being built with varying distances between joints in an endeavor to determine how few can be used with success.

The average cost of this type in New York State for 6" depth of pavement is $1.121 per square yard of pavement only. Total average cost for mile of completed highway, including excavation, drainage structures and pavement, is $15,320 (1916).

Small Stone Block Surfacing.—In Germany, Hungary, Austria, and England a surfacing made of granite blocks, ranging in size from 2½" to 4", has been used successfully. This pavement is known as Kleinpflaster in Germany, and as "Durax" armoring in England. The stone cubes must be cut with considerable accuracy in order to give a smooth and durable surface.

The blocks are laid on a thin sand cushion of about ⅜" depth, on either a macadam or concrete foundation; they are thoroughly rammed to give a firm bearing and the joints filled either with clean sand flushed in, or a bituminous filler. The joints do not exceed ¼" in width. The courses of cubes are laid either diagonally to the direction of the traffic or in concentric rings.

Where the stone is broken by hand the cost is high and it would be impossible to consider its use for rural roads in this country. A machine[1] has, however, been developed in Europe for breaking these cubes which is claimed to produce a satisfactory product at a reasonable rate. It is a belt-driven friction drop-hammer having a stone chisel mounted on the anvil; the hammer head is shaped like a stone-cutter's sledge. The power needed for each machine is about 1½ h.p.

About 400 of these machines are in operation, and a plant in Sweden is turning out 700,000 square yards of pavement per year with 62 machines.

Provided the pavement can be laid for $1.00 to $1.25 per square yard, it seems a type that must be seriously considered. A price as low as this, however, would necessitate the use of convict labor in the manufacture of the cubes.

McCLINTOCK CUBE PAVEMENTS

By W. G. Harger

This is a patented pavement devised by J. Y. McClintock, County Engineer of Monroe County, N. Y. It is very similar to "Kleinpflaster" except that under his patent artificial cubes as well as stone cubes are proposed. It appears to be a very promising type.

[1] A detailed description of this machine is given in *Engineering News*, March 27, 1912.

The construction is essentially as shown in Figure 40 and consists of a top course of $2\frac{1}{4}''$ cubes placed on a thin sand cushion supported by either a macadam or concrete base. The cubes have been made of concrete, vitrified paving brick material and stone as in Continental practice.

They are loaded, hauled and dumped like broken stone; laid in close contact by means of a pallet and rake 128 at a time on a sand cushion $\frac{1}{4}$ to $\frac{1}{2}''$ thick, no care being taken to break joints. They are then rolled to bring to an even and firm bearing; the joints are filled with a sandy loam and the surface treated with a light coat of light road oil or cold tar if the foundation is macadam. The joints are grouted if the foundation is concrete. Temporary shoulders of 2″ plank are put down during the laying of the cubes after which they are removed and replaced with broken stone or gravel as shown in Figure 40.

The experience of the past six years has shown that this form of construction using a sand-tarred joint is flexible under frost action which makes it suitable as a surfacing on a macadam base. It keeps its shape under traffic and shows no tendency to ravel or break down at the edges and can be successfully held with a macadam or gravel shoulder without the formation of a rut

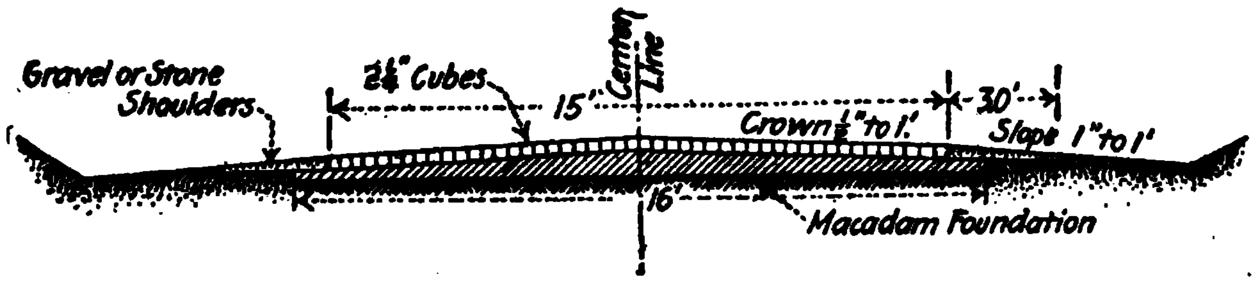


FIG. 40.

along the edge which is a difficulty always encountered where a rigid edging is designed. It gives a satisfactory surface in both wet and dry weather and can be laid late in the season. The cubes require comparatively little inspection and can be successfully used as a patch in maintenance with simple manipulation. They reduce the tonnage and freight cost where imported materials are required. Concrete cubes have not served satisfactorily, failing in spots, but this is to be expected as it is not a reliable material for a road surfacing of this nature (that is for such small units). Vitrified shale cubes with wide sand joints laid on a macadam base have shown ability to stand medium traffic. Vitrified shale cubes with close tarred joints laid on a thick macadam base serve very satisfactorily under moderately heavy traffic, and the indications are that these cubes laid on a concrete foundation and grouted will meet all but the heaviest traffic satisfactorily.

Consider briefly the present tendencies in highway construction. There are two distinct types: the flexible form represented by the macadams and the rigid types, such as brick, asphalt, stone block, etc., having concrete foundations. Each has a distinct field and their relative economy depends largely on the traffic.

It is sufficient for this discussion to note that macadams are suitable for light and medium traffic (Classes II and III); that they are able to withstand climatic changes better than the rigid pavements and that with a moderate yearly expenditure they can be kept in good condition when used under the volume of traffic stipulated.

They fail either under high velocity traffic or heavy hauling; the first being a surface failure and the second a foundation failure for most of the roads in this locality but a surface failure for some which have a thick well consolidated base. That is, if some better flexible surface can be used on a first-class macadam foundation, this type of road will be able to handle a heavier volume of traffic than at present with a moderate maintenance charge. The indications are that the brick cubes with sand-oiled joints will serve this purpose.

The rigid roads develop defects due to temperature changes; frost heave and the settlement of fills. Subsequent movement is localized along these lines and eventually expensive repair and reconstruction is necessary. Under heavy traffic, however, the cost is less than for the macadam type and the inconvenience of continual repairs is avoided.

The first cost of brick and asphalt block which are generally considered the best of the rigid types is so high that designers often hesitate to use them where they are actually needed. If it were possible to reduce the cost and yet obtain practically the same class of improvement a larger mileage could be used to advantage.

The indications are that the brick cubes on a concrete foundation will serve this purpose at a cost of about $0.40 per square yard less than the present paving brick.

Highway designers do not hesitate to use macadam for the light traffic roads or expensive rigid constructions for the extremely heavy traffic; the great mileage that lies on the verge of either form of construction offers the real difficulty. It is for this class of road that the cubes are particularly adapted by reducing the cost of brick and increasing the efficiency of macadam. This applies also to the resurfacing of concrete and macadam roads.

The author believes that provided this type fulfils its present indications that it will meet a recognized need in highway construction and for this reason has given more space than perhaps is justified to a method which has not been tested out by a large mileage of construction.

A reasonable cost of the brick 2″ cube surfacing is approximately $0.95 per square yard in Western New York. This form of road material is adaptable to manufacture by convict labor.

Rocmac.—Rocmac is another patented pavement which deserves mention, as the roads which the author has seen built by this method compare favorably with other types of construction. The claim is made that, under favorable conditions, it will cost only fifteen cents per square yard more than plain macadam. The only available example of cost details given below is hardly a fair sample of what can be done.

We quote an extract from the 1910 report of the New York State Highway Commission:

"Experimental pavement according to the Rocmac System as laid over the westerly portion of Buffalo Road, Section No. 2, County Highway No. 83, located in the Town of Gates, County of Monroe, New York.

"The Rocmac system differs from ordinary macadam construction in that the aggregate of crushed stone is cemented together by a matrix composed of limestone dust (as rich as possible in carbonate of lime) mixed with a solution of silicate of soda and sugar, the silicate of soda combining with the carbonate of lime, an unstable compound, forming silicate of lime, which is a very stable compound.

"The materials used in this experiment were Leroy limestone flour for the matrix, being the entire crusher product which would pass a screen of ¼ in. mesh, and Akron limestone No. 3 size with some No. 4 size mixed for the aggregate. The No. 3 size being retained on a screen of 1¼ in. mesh and passing a screen of 2 in. mesh, the No. 4 size being retained on a screen of 2 in. mesh and passing a screen of 3½ in. mesh.

"The delivery point for material shipped by rail being Coldwater Station, a dead haul of one mile to the beginning of the work.

"The supervision given this work consisted of occasional inspections by the divisions superintendent of repairs and the inspector in charge of this section, neither of whom could devote much time to this particular work without interfering with other duties. Had the work been constantly directed by a competent foreman more progress would have been made and the cost probably would have been decreased.

"The method pursued during the laying of this surface was to scarify by hand the original foundation course, removing all loose material by brooming, upon this prepared foundation so spread the matrix composed of limestone dust and solution, to an average depth of about 2 inches, upon this spread the crushed limestone aggregate to such a depth as would give finished rolled thickness averaging about 3¾ inches when properly crowned, then rolling same until thoroughly consolidated and continuing rolling and sprinkling with water by hand until the matrix which flushed to the surface in the form of grout has nearly disappeared, when the pavement is covered with a light coat of screenings and considered complete.

"The total length of this resurfacing extending from Station 237 to Station 275–76 is 3876 lineal feet, aggregating an area of 6890 square yards surface upon which was used 1004 tons of No. 3 and No. 4 crushed limestone, 520 tons of limestone flour and 4050 gallons of silicate of soda solution.

"Deducting from total expenditure materials not used and expense of labor trimming shoulders and ditching would leave total cost of this resurfacing, including all material and labor necessary to form pavement complete in place $6400.82 or $0.9288 per square yard.

"This expense is itemized as follows:

Item	Total	Per Square Yard
Cost of stone f.o.b. cars delivery point	$2026.59	$0.2941
Cost of Rocmac solution	617.28	0.0896
Cost of teams hauling stone, solution, water and coal	1408.79	0.2044
Freight and duty on solution	408.61	0.0593
Roller and coal	547.28	0.0794
Labor	1341.64	0.1947
Tools, tanks, blacksmith, oil and wood	50.63	0.0074
Total	$ 6400.82	$0.9288

"The average price paid per ton for all stone f.o.b. cars at delivery point is $1.25½; price paid per hour for labor $0.22; for teams $0.56¼ per hour; roller rent $10 per day.

"During the progress of this resurfacing traffic was not intefered with at all, all traffic being permitted to go over the work in whatever stage of progress. This is an advantage worthy of consideration.

"The finished surface after five months' traffic has the appearance of a well-constructed macadam road, being hard, smooth, well bound, and clean, no discoloration being apparent except immediately after a rain, when it shows light brown in spots, due to the solution, which being soluble in water comes to the surface.

"No ravel developed during continued dry weather when freshly laid and under traffic; road is relatively dustless; this, however, depends upon the percentage of silica in the stone used. The theory being that whenever the pavement becomes wet the solution is brought to the surface, resulting in absorbing and hardening down any fine material which had been produced by the abrasion of tires.

"It can be laid in all excepting freezing weather, and while smooth yet it is sufficiently rough to afford good footing for horses and rubber tires. There is nothing entering into the construction to soften under high temperature and nothing to form mud in wet weather. It is claimed to be self-healing, due to continual chemical reactions taking place whenever the road becomes wet."

Conclusion.—In this chapter the authors have attempted to show the approximate cost of the different styles of construction in general use or such experimental tops which they have seen which promise well. The costs given are relative only, to be used in the comparison of the various constructions and are based on roads in New York during the period of 1912 to 1915.

The data may be summarized as follows, showing the desirable requirements, location and approximate first cost of the different constructions. The comparative yearly costs including maintenance and renewal are shown in Table 22 compiled from maintenance data. The type selection shown in Table 21C does not consider the requirements of steep grades.

On steep grades stone block is the best solution, hillside brick second, penetration one coat pour bituminous macadam third, and waterbound macadam fourth. The last two become slippery if maintained by surface oiling and it has been necessary in some cases to build a specially wide shoulder treated with gravel or stone for horse traffic.

Classification for Safety of Traffic

The sheet asphalts, topeka mix and similar constructions are dangerous for high speed traffic even on fairly level grades during sleet storms or light rains and are not recommended for roads outside of villages.

Bituminous macadams, concrete, brick, stone block, waterbound macadams and small stone or brick cubes can be ranked as safe surfaces for high speed traffic.

Recommended Types.—Bituminous macadams are recommended for Class II and IV traffic and resident village streets.

Waterbound macadam for Class III traffic.

Concrete for Class I outside of villages.

Brick for Village business streets.

Stone block for hills on Class I traffic.

Asphalt block for extremely heavy Class I traffic.

Sheet Asphalt, Topeka, etc., are to be avoided where traffic travels at high speed. Its most suitable location is a resident village or city street.

FAILURES

The common causes of failure of different pavements due to structural defects are as follows. The details of inspection are taken up in Chapter XV.

Stone Block.—Failures rare; will stand lots of abuse in construction.

Asphalt Block.—Failures rare. When they occur due to poor block.

Waterbound Macadam.—Failures rare. When they occur are generally due to poor rock, small sized stone in top courses, and insufficient rolling or puddling.

Penetration Bituminous Macadam.—Failures not uncommon due to the use of too much soft binder; unequal application and overheating of Binder. The asphalt companies advocate the use of too much bitumen.

Concrete.—Failures not uncommon due to inferior materials particularly dirty sand and to poor manipulation, weak mix, and too much water content.

Brick.—Failures not uncommon due to poor brick and careless grouting.

Sheet Asphalt and Topeka Mix.—Failures not uncommon due to overheating and poor mix.

TABLE 21C.—CLASS I TRAFFIC

Suitable Pavements	Recommended Min. Width of Pavement Proper	Total Depth Including Base	Approx. Cost per sq. yd. Including Base	Approx. Cost per Mile Including all Grading, Draining, Incidentals, Etc.	Best Location if Used
Stone block on concrete	18′	13″	$3.00	$36,000	Anywhere except resident sections of villages.
Asphalt block on concrete	18′	9″	2.20	28,000	Anywhere.
First-class cement concrete	18′	8″	1.60	20,000	Outside of villages.
Brick on concrete	18′	10″	2.00	26,000	Village streets.
Asphalt concrete	18′	8″	1.70	22,000	" "
CLASS II TRAFFIC					
First-class concrete	18′	7″	$1.40	$18,000	Outside of villages.
Small brick cubes on macadam or concrete	15′ plus stone shoulder	12″	1.50	17,000	" " "
Bituminous macadam	15′ " " "	12″	1.20	14,000	Anywhere.
Tarred waterbound macadam	15′ " " "	12″	1.00	12,000	"
CLASS III TRAFFIC					
Waterbound macadam treated with calcium chloride or light oil.	14′	9″	$0.70	$9,000	Anywhere.
	10′ plus gravel shoulder	10″	0.80	8,000	"

CLASS IV TRAFFIC

Asphalt concrete	16′	plus shoulder	8″	$1.70	$20,000	Anywhere.
First-class concrete	16′	" "	7″	1.40	17,000	"
Amiesite on macadam or concrete	16′	" "	10″	1.60	18,500	"
Bituminous macadam	15′	" "	10″	1.00	12,500	"
Waterbound macadam oiled	15′	" "	10″	0.80	10,500	"

NOTE.—It will be noted that this table provides for a heavy depth of macadam suitable for modern traffic loads and special shoulder treatment on Class II and IV.

TABLE No. 22.—SUMMARY SHOWING APPROXIMATE YEARLY COST PER MILE OF DIFFERENT KINDS OF ROADS

Type of Pavement	Width and Thickness Including Base		Class of Traffic	First Cost per mile including Grading, Pavement, Drainage and all Incidentals	4% Yearly interest on First Cost	Approx. Yearly Maintenance including Oiling	Assumed length of life Years	Cost of Resurfacing, distributed over probable life on Road on Yearly Basis	Total Cost per mile per Year
	Width	Thickness							
Stone block.......	18′	13″	I	$36,000	$1,440	$150	35	$ 700	$2,300
Asphalt block.	18′	9″	I	28,000	1,120	150	25	800	2,100
Asphaltic concrete.	18′	8″	I–IV	22,000	880	300	10	1,200	2,400
Brick ...	18′	10″	I	26,000	1,040	150	15	1,100	2,300
First-class cement concrete.... ...	18′	8″	I	20,000	800	150	12	1,100	2,050
First-class cement concrete...... ..	18′	7″	IIA–IV	18,000	720	100	15	800	1,600
Bituminous mac.	15′	12″	II–IIA–IV	14,000	560	350	10	550	1,450
Water mac. tarred.	15′	12″	II	12,000	480	450	7	500	1,450
Water mac. oiled or treated with calcium chloride..	14′	9″	III	9,000	360	350	10	400	1,110
Water mac. calcium and oiled	10′	10″	III	8,000	320	350	10	350	1,000
First-class cement concrete	10′	6″	III	12,000	480	200	15	550	1,250

NOTE.—It can be seen that our experience indicates that the selection of type has very little effect on final cost and that for,
Class I Traffic (interest, maintenance and renewal is approximately $2200 per mile per year.
Class II Traffic (interest, maintenance and renewal is approximately $1600 per mile per year.
Class III Traffic (interest, maintenance and renewal is approximately $1100 per mile per year.

To afford a comparison of high and low type roads the following data is inserted at this point for Earth, Gravel, and Sand Clay roads.

Type	Approx. Cost per mile	4% Interest on First Cost	Approx. Yearly Maintenance and Renewal	Total Yearly Cost Per mile
Earth........	$2000	$ 80	$ 50	$130
Sand Clay....	3000	120	75	200
Gravel........	4000	160	240	400

CHAPTER VII

MAINTENANCE

Maintenance will be divided into two classes: the care of low type (earth, sand-clay and gravel) roads and the more costly attention required to keep the higher type macadams and rigid pavements in good condition. Maintenance is a relative term and the costs given in reports mean very little unless each man personally understands the conditions under which the work was done and the degree of perfection in maintenance attained.

The authors have had no personal experience in earth or sand-clay maintenance work; the data pertaining to these types is compiled data and while the explanation of methods are clear and definite the general costs must be accepted merely as approximate. The data on maintenance of high type roads is based on our personal experience and while this may limit its general application somewhat it is more definite in the matter of costs and more valuable than the ordinary State Reports which often are difficult to interpret correctly, due to indefinite bookkeeping and to the transferral of charges between various funds.

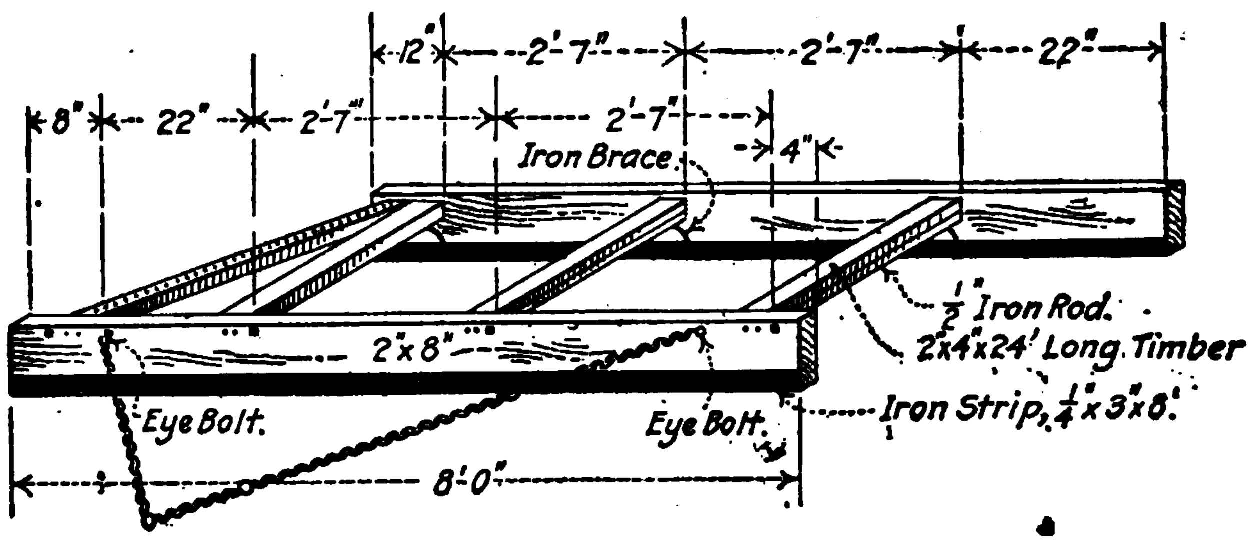


FIG. 41.

Low Type Roads.—The maintenance of these roads consists in keeping the grass and weeds cut, the ditches clean, culverts clear, overhanging trees trimmed and the surface of the traveled way scrapped and dragged. One shaping with a blade road machine in the spring generally is all the heavy work required the rest of the work being done with road drags, hones, planers, etc., at frequent intervals during the balance of the year. On sand-clay and gravel roads surfacing material is added to fill holes and ruts or better the wearing surface.

There are two general systems: the contract system which lets short strips of road not over 4 miles in length to farmers long the road and the patrol system which is taken care of by a steady patrol gang which handles from 10 to 20 miles. The contract system is explained in the quotation from the 1917 Year Book of the American Highway Association, page 196. The patrol system is referred to throughout the chapter in various quotations.

Earth Roads.—Road machine blade scrappers are familiar to all readers. The road hones, planers, etc., are not so well known and their construction is shown in Figures No. 41–41D. Steel drags ican now be obtained. Their use in earth or gravel road maintenance is explained in the following quotation from the United States Forest Road Manual.

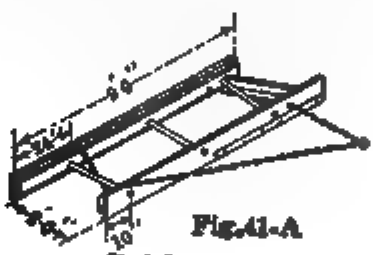


Fig. 41-A

Plank Drag

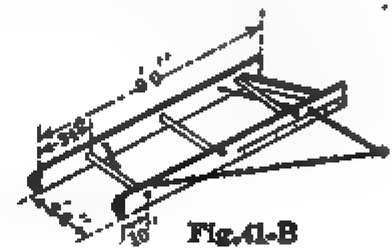


Fig. 41-B

Split Log or "King" Drag

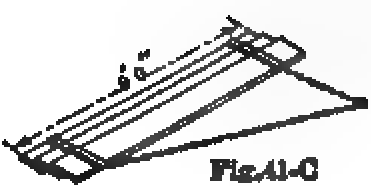


Fig. 41-C

Log Drag or Smoother

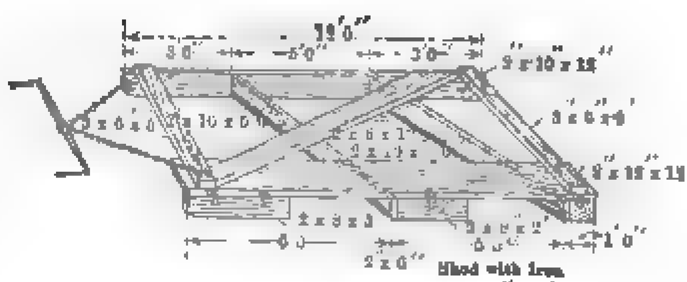


Fig. 41-D

MAINTENANCE

"Maintenance is the most important item of work to be considered in road management. The smaller allowances for systematic maintenance, as they are being included in the annual road budget alongside the unlimited number of those for periodical repairs, tend to give it a place of least consideration and again its consideration and planning is evaded as much as possible for it is the never-ending consideration of continuous annual work and expense. It is always admitted that the degree of efficient use we derive from anything constructed for practical utilization, depends on the amount of effective maintenance it receives. Therefore, roads which are most widely used and exposed in all their parts to the worst of elements relatively should receive the highest degree of such attention, and moreover the higher the type of construction and the more it costs, the more marked attention will it require.

"However, it is most gratifying to find that the old ideas of taxpayer and user are rapidly disappearing, making way for the installation of practical system for the efficient retention of the better roads—as they are now being constructed. Gradually are we beginning to learn that the stability and usefulness of a road is not forever established, even when the best of supervision and authorities declare and approve or have made the construction strictly up to the standard and with ample drainage provided—but that each mile of construction should be followed immediately with a mile of maintenance. Besides eliminating the difficulties and discomforts of travel,

which seems only a benefit to the traveler, but is in reality an economical benefit to everyone, directly or indirectly—maintenance will do away with all the worries to the management and effectively prevent so much of this misapplied criticism to construction features. Finally the results of maintenance encourage more road-building, whereas its lack discourages it.

"There is no type of road that can be considered permanent, and an earth road or one bedded in the natural material, which is wholly as important as the higher grade roads, or even more so—is the cheapest to maintain in its original condition. The complete maintenance of an earth road means simply the retention of the drainage facilities that were provided in a completed and properly constructed piece of road work. Furthermore the experience of and the attention given to the road in constant maintenance will show where ample drainage was not sufficiently provided; and again showing its importance, constant maintenance secures this necessary drainage with the least costs and at the proper time—before serious damage is done and heavy repair costs result. The time to begin the maintenance is immediately after the road is constructed, and its degree of efficiency will depend on what in the way of money or assistance is constantly provided or made available to meet sudden contingencies. The work must be done at the right time and in the right way to get the best results.

"Ample drainage begins with taking the water off the road and continues with taking it along the road and away from the road. Constant maintenance by dragging secures this primary step in the drainage system, and also a hard and smooth surface for travel. The dragging preserves the crown, which is kept in the traveled way for no other purpose than to shed water. It then follows that this water will be taken away from the road through the further efforts of constant maintenance in keeping the ditches and culverts open.

"To properly and economically maintain a certain road or set of roads an organization for doing the work should be effected. On a country or mountain road a patrol consisting of two teams and two men for one part and one team and one man for the other part of the season should be able to care for 15 to 20 miles. It will be found though that a newly constructed road will require heavier maintenance for the first year or two, thus reducing the number of miles for this patrol. One or more such outfits could be applied to a longer road or a larger system and kept under the same supervision. These patrols keep the ditches clean and the culverts open, haul surfacing materials, *i.e.*, clay onto sandy portions and sand or gravel onto clay, keep the right-of-way open to sun and wind; and are on hand to drag the road after each rain. Two teams are provided only in cases where there is no extra help available along the road to assist in the dragging, otherwise one team would be sufficient. However, if the teams are government-owned, two teams should be had, as the added costs for the extra team are small and will in most cases prove cheaper than hiring. The two teams can be used on one drag or two depending on the ruling grades in the road.

"In early spring when the winter snows are going off, the supervision and such extra assistance as is necessary should be made available early to see that the snow water is being cared for—that it is running down the ditches and into the culverts, and not down the wheel tracks and over the banks of the road. Later he should have a small gang of men making the necessary repairs that might occur while the frost is coming out of the ground and from wash and water-breaks. A light grader should be at hand especially on sidehill roads to clean the ditches of material broken off or rolled down the banks and to restore badly depleted crowns, after which the drag can be used for the remainder of the season to preserve this perfected condition.

"A good foreman for this should be a man who as well as to take a hand in the work, should be able to plan the work and keep in touch with the maintenance needs and move his men economically to the first necessary pieces of repairs.

"Dragging is the cheapest and most effective method of maintaining roads constructed of earth, top soil, sand-clay or gravel. The drag is a very simple and inexpensive implement and when used properly gives surprising results.

"Properly used and at the right time the road drag performs four distinct offices. (1) By moving at an angle to the traveled way it tends to produce or preserve a crowned cross-section; (2) if used when the material of the

surface is not compact and hard, it tends to reduce ruts and other irregularities in the road by moving material from points which are relatively high to those which are relatively low; (3) when used after a rain it accelerates the drying out of the road by spreading out puddles of water and thus increasing the surfaces exposed to evaporation; (4) if the surface material is in a slightly plastic state, dragging smears over and partially seals the so-called pores which naturally occur in earthy material, and thus makes the road surface more or less impervious to water.

"If used improperly or at the wrong time, the drag may do actual injury to a road. Dragging a very dry road, for example, serves to increase the quantity of dust and may do additional damage by destroying the seal produced during previous draggings. If, on the other hand, the road is very wet and muddy, the irregularities in the surface are likely to be increased rather than diminished. The common defect in road dragging is to regard the road drag as a road-building tool, and to expect one or two trips to put the road in shape for the season.

Notes on Maintenance

"1. In filling bad ruts and mud-holes, it is best to use the same material that the roadbed is composed of, otherwise an uneven surface will result, oftentimes, of course, the roadbed of clay can be improved by scattering sand or gravel over it more or less evenly, or if of sand by the same use of clay, but not by filling the ruts with these applications. Filling with rock will effectively close a mud-hole but the next season will find two more mud-holes, one on either side of this hard place formed by filling the first.

"2. On sidehill roads, after light snows have fallen during the season, the inside ditches should be opened of the snow immediately in order that the water from the melting snow will run down the ditches instead of the wheel tracks. This is especially necessary where steep grades occur to prevent heavy wash and loss of crown in the traveled way, and water breaking over the outside bank. The snows, usually, being light, this can be done by drawing the drag down the ditch with a large skew angle or better with a small ditch-cleaner, the A-drag or go-devil.

"3. In a grazing country very often it occurs that salting grounds have been used near or along the roads. These should be removed for cattle climbing up and down the banks and walking along the ditches can cause considerable unnecessary damage to the road. During the season of cattle or sheep drives the men on maintenance should see to it, that the herds or bands, if they have to use the road, use the traveled way and not the banks and do as little damage as possible. If serious damage is done they can make immediate reports, if owners are obligated to repair such damages on public roads.

"4. Outer bank slopes of earth that are continually eroding, should be protected by sowing to grass, or any other plant that will mat and not be objectionable to occupants of lands along the road.

"5. Keep the ends of the culverts free from drifting weeds and débris and clean the catch-basins of silt and other deposits.

"6. Remember that the chief repairs should be looked after in the spring when the soil, being moist and easily worked, will compact readily under the drag and traffic. There is little use in attempting to do much in July and August to the roadbed proper, for the soil is so dry that it is difficult to shape properly anctmost of that moved will blow away in the first wind.

Notes on Dragging

"1. Use the drag often and if the very best results do not come at first trial, do not quit. First-class results can be attained.

"2. Dragging is always done after rains, melting snows, or thaws, just after the ground has lost its stickiness, when the material will slide easily along the face of the drag and pack well; but not when it becomes dry in any one place. Different road surfaces and varying conditions will demand different times of application, the knowledge of which will come through faithful and persistent use and observation.

"3. It requires a careful and skilful operator to get good and quick results, one who knows or can learn how to hitch to it, and where and how to ride it. Hitch so that the drag will travel at an angle of 45° with the

center line of the road, and do not try to cut too much material at one operation. The amount moved depends wholly upon the length of hitch and position of driver. A long hitch will move more earth than a short one. When a hard spot must be cut, the driver throws all his weight on the front blade; when a low place must be filled he moves back. These operations on patented steel drags are facilitated by changing the angle of the blades from a vertical. Step quickly to the opposite end of the drag from which you wish to deposit material into low spots.

"4. Drive the team at a walk and ride the entire distance. The drag should begin at the ditch line and proceed toward the center or crown. If the crown becomes too great, reverse the skew angle of the drag. Do not try to drag too wide a section at one operation.

"5. Do not try to drag too long a section. So much depends on the time the drag is used, that there is danger of dragging the road too wet at one end and too dry at the other. Learn to select those sections which dry before others and drag them first.

"6. Drag the road during or directly after one of the light snow falls just before it freezes up for the first time, as it will be in better condition to go through the winter and better able to shed water during the spring thaw.

"7. Very little improvement will be noticed after the first trial, and many trips will have to be made the first year after construction. The second year, less dragging will be required and the road ought to improve continually."

The following quotation from the 1917 Good Roads Year Book shows the Kentucky methods and approximate cost of maintenance.

"Maintenance by dragging is most successful when well organized. The results obtained by good management in Hopkins County, Kentucky, are frequently cited as indications of this, and for this reason the following account of the work there is quoted from a report by the Kentucky department of highways.

"In 1912 a county engineer was appointed. The county roads were measured under his supervision and 2 mile sections designated, and in January, 1913, drags were started on about 100 miles of the county roads. This original contract was only for dragging the roads, which work was to be done four times between January 1st and April 1st, at a cost of $10 to $12 per mile. As the sections dragged were not continuous, the citizens at once appreciated the difference between the maintained road and that which was not maintained. Consequently the next contract, which called for dragging and also for cleaning the ditches for six months, until November, 1913, resulted in contracts for 150 miles of road and at a reduced cost. In November, 1913, a contract substantially like that now in use was adopted and the time of the contract was for one year, or until November, 1914. Over 200 miles were maintained this year at an average cost of $28 per year per mile. For the year from November, 1914, to November, 1915, the benefit of the maintained roads was so well understood by the citizens that 560 miles were under contract at an average cost of $24.35 per mile per year.

"In November, 1915, a two-year contract was entered into, which the county may revoke for non-performance of the obligation at the end of the first year. About 520 miles are now under contract, at prices ranging from $12 to $40 per mile per year, the average being $22.10. It is expected this mileage will soon be increased. Originally a contractor was allowed to have charge of 8 miles, but now he is not allowed to contract for more than 4 miles of road. Under the 1915 contracts the contractor must trim the branches which overhang and interfere with travel on the roadway; keep the roadway between ditches free from shrubbery and weeds; keep the ditches clean, free from obstructions, and at all times capable of carrying the water. 'He shall by June 1st each year grade the roads with dump scraper, grader, drag and ditcher, or in any way he may see fit, so that the center of the roadway shall be crowned so that the water will flow from the center of the road to the side ditches, and at no place will the water stand on the road or run down the road. The road shall be dragged from ditch to ditch at each dragging, when the road is wet, but not sticky.'

"A record of the number of draggings is kept by the county engineer on cards which, before mailing by the contractor, are countersigned by the

rural route carrier or a reliable citizen. The contractor also hauls material and constructs all culverts and bridges of 10 ft. span or under, and keeps the approaches to and the floors and abutments of all bridges and culverts on his road in good traveling condition. An analysis of these contracts shows that where the contract has been faithfully executed there is a decrease each year in the cost per mile, mainly because the farmer contractor has learned from experience that continuous maintenance makes a lower cost of time and labor each succeeding year."

Cost.—The cost of earth road maintenance ranges from $20 to $200 per mile per year. A fair average is approximately $50 per mile per year for ordinary farming county and $100 per mile per year for mountain roads.

Sand-clay Roads.—The methods and character of work are the same for the sand-clay maintenance as for ordinary earth roads. The cost is generally less. The following quotation from the Alabama State Highway Report indicates the usual procedure.

Sand-clay Roads

"No cheap road can be maintained as easily and at as small an annual cost as a well constructed sand-clay road. It responds readily to a road machine and the surfacing material is usually very convenient. Like all others though it is neglected until extensive and expensive repairs become necessary. If a sand-clay road which has been intelligently constructed is kept dragged at reasonable frequent intervals, say three times a month during December, January, February, March and April, and during rainy periods in the other months, it will give excellent service and serve all practical purposes. If too much sand is in the surfacing material the road will tend to ravel or disintegrate and it becomes necessary to add a small amount of clay to the sandy section. A thorough harrowing should then be given the surface, after which the road should be thoroughly machined or dragged until the proper cross-section is obtained. Likewise, too much clay may develop in wet weather and the addition of sand becomes necessary. Sand can be incorporated in like manner as the clay. In very wet weather, traffic will incorporate the sand fairly well and it frequently becomes necessary to add sand to prevent slipping, when artificial mixing would be difficult."

Gravel Roads.—Gravel roads require patrol maintenance for good results. The road should be shaped with a road machine blade grader in the spring while soft and plastic and kept in shape by dragging. Gravel must be added continuously to fill holes and ruts. Shoulder, ditch and culvert routine cleaning is the same as for any maintenance.

The following quotation is from Instructions to Patrolmen in New Hampshire which is famous for its gravel roads.

"Each patrolman must supply a horse and dump cart, shovel, pick, hoe, rake, stone-hook, axe, iron bar, iron chain and tamp. Special tools are furnished by the State Highway Department.

"One dragging in the spring is worth two in the summer. It is better to drag a mile of road several times and get it in good condition, than to drag 2 or 3 miles and not finish any part of it. Don't drag a soft section when it is so wet that the first vehicle to pass will rut it all up. First fill the holes and ruts with new material and then drag as the surface dries out. Every patrolman should have material dumped in small piles along the side of his section so that on a rainy day he can at once fill all holes and ruts in which water is collecting.

"When the weather is unsuitable for dragging, as during a dry spell, all patrolmen should cart on all the new material possible in order to fill all ruts and holes and resurface worn sections. Carting is very essential

during dry periods and should never be neglected. Whenever a patrolman is in doubt as to what to do next the general rule is to cart new material, for all roads are wearing out under travel and it is necessary that the surface be continually renewed to take the place of the old material that is thrown out as mud or blown away as dust.

"Save all the sods, leaves, rubbish, stones and refuse that you clean off your road and dump this waste material in places where the bank is steep so that by flattening the side slope there will be no need of a guard-rail, or dump the material back of a present guard-rail so that later this guard-rail can be removed."

The necessity for patrol maintenance is shown by the following extract from the Iowa Specifications.

Maintenance of Gravel Roads

"County engineers' and supervisors' attention is called to the fact that both Class A and Class B gravel roads require constant and systematic maintenance at all times. Special attention should be given such roads for the first year following their construction. During this period the gravel is sure to become rutted, wavy, and scattered if it is not maintained in the most careful manner.

"Hauling gravel and dumping it on the road does not produce a gravel road. The most important part of the construction work lies in the attention which the road received while the gravel is being compacted. A road newly surfaced with gravel is nothing but a possibility. The success or failure of such a possibility depends very largely on the attention which it receives during its first year. The frequent use of a planer or blade grader will prevent the formation of ruts and waves. This work should be done while the gravel is wet, as better results will be secured.

"The scattered gravel should be brought back on the surfacing and the earth shoulders built up to hold this material in place. Additional gravel should be added to replace that worn away and to fill any depressions due to settlement.

"The Commission strongly urges that the patrol system of maintenance be adopted for all gravel roads. The patrolman should spend all his time on the road. It is only by such a system that definite responsibility can be fixed. Patrol maintenance should extend not only over the first year after the gravel surface is placed, but also throughout the succeeding years. It should extend to the side ditches, earth shoulders, culverts, and all other parts of the road as well as to the gravel surfacing.

"While the patrol system of maintenance is urged for all gravel roads, it is absolutely necessary for Class B gravel roads. These specifications have been prepared with that idea in mind.

"The Commission will approve the construction of Class B gravel roads on the county system only on condition that an adequate patrol maintenance will be established promptly after such road is placed in service."

IOWA HIGHWAY COMMISSION.

Cost.—We are indebted to Mr. F. R. White, Road Engineer of the Iowa Highway Commission for the following information in regard to the construction and maintenance cost of about 400 miles of Class B gravel roads (see Plate No. 39, page 140). These roads were constructed at a cost slightly above $1000 per mile. The cost of maintenance depends very largely on the volume of traffic and the location of gravel. However, where there is an average of 200 to 300 vehicles per day and the gravel can be obtained within 3 miles of the road the yearly cost of maintenance is about $150 per mile.

In New York State where the roads are oiled to care for a somewhat larger volume of traffic 200 miles of high-class gravel roads cost approximately $550 per mile per year to maintain.

A fair average maintenance cost per mile per year for double track gravel roads is probably from $200 to $300 under fairly heavy travel.

HIGH TYPE ROAD MAINTENANCE

In the development of any system of highways the methods and cost of maintenance become increasingly important. The rapid growth of motor traffic in the last few years has changed both methods and cost making it necessary to give new figures which are reliable for present traffic conditions. We have therefore confined ourselves in the discussion to recent costs with which we are familiar in order that in stating general conclusions proper allowance is made for unusual conditions not shown in the reports of various State Highway Departments.

The discussion will be based on the general maintenance costs and methods employed on 6000 miles of New York State improved Highways of all types for the years 1915 and 1917 and detail costs on 600 miles of roads in Western New York for a term of years.

We are indebted to Mr. Frank Bristow for the following discussion of general maintenance methods and summarized costs. It should be borne in mind that the discussion and costs apply to territory subjected to severe winters.

MAINTENANCE OF MACADAM AND RIGID PAVEMENT HIGHWAYS

By Frank W. Bristow

N. Y. S. Dept. of Highways, Division on Maintenance

Maintenance comprises keeping the paved roadway surface in as nearly perfect condition as possible, keeping the earth shoulders smooth and safe for traffic; the drainage system free from obstructions; all structures in good repair; removing obstacles to vision as brush or overhanging branches; and cutting tall weeds and grass.

If the work of maintaining improved roadways is consistently performed through successive years it is certain that the efficient life of such roads will be lengthened. Maintenance should commence when construction leaves off, because in order to effectively and economically maintain improved roads it is necessary that the roadway be in a good state of repair at the time the maintenance work begins, and should the pavement be so worn as to be structurally weak it is not economy to postpone resurfacing.

Maintenance work, including surface treatment with bituminous material and cover, should be distinguished from extensive repairs involving replacing of wearing course or reconstruction.

Maintenance of Macadam Roads

It is especially desirable that all surface treatments be completed as early in the season as possible; say by mid-summer to permit

traffic to enjoy the greatest benefit from such treatment, the season of heaviest motor traffic being from the middle of July to the middle of September. So far as practicable the correction of surface defects such as ruts and depressions should precede the surface treatments.

While the elimination of dust on macadam roads is desirable as adding to the comfort of the traveling public, it is necessary from the maintenance point of view, inasmuch as dust means deterioration of the road which if permitted to continue results in a raveled condition and the macadam will disintegrate. Surface treatment with oil or tar also tends to seal or waterproof the pavement. Horse-drawn steel-tired traffic tends to destroy an oiled surface mat, while rubber-tired motor traffic is beneficial.

It is good practice not to oil macadam roads upon which horse-drawn traffic greatly predominates or new waterbound macadam which has not been under traffic at least two months, or extremely shady roads.

The usual foundation defects which develop in gravel and macadam surfaces are ruts, due to a soft condition in the earth sub-grade, depressions due to settlement of fills which commonly develop at locations where new culverts were constructed and frost boils.

Shallow ruts and surface depressions are corrected by being filled in with crushed stone of as large size as the depth of depressions will permit, the same being well tamped into place, and more lasting results are obtained if a proper grade of bituminous material is used to firmly bind the new stone; light asphaltic oils and tars have been used for this purpose with unsatisfactory results, in that patches made by this method do not endure, the experience being that the material forming the patch is pushed ahead by traffic leaving the original depression exaggerated by the bunch of new patching material at the end. Heavier binder grade material has been used; a patch by this method is durable but does not wear away as rapidly as the adjacent surface resulting in a high spot in time. To date our experience is that an asphaltic emulsion for cold patching is most satisfactory, being nearly fool proof and requiring no equipment but a broom and shovel. This material is not recommended for use with stone of greater size than will pass a one and a quarter inch ring. In using this material the depression to be repaired should be swept clean, so as to be free from mud or loose material, and tamped full of a mixture of the emulsion and broken stone. Such a patch will require an hour or two to set. The proportions of the mixture required are, where the stone used are uniform in size, about three-quarters of a gallon per cubic foot of stone; where the stone are graded about a gallon per cubic foot. This mixture may be made in moderate quantities as stock for use is required. Ruts in gravel surfaces may be eliminated by the use of a hone early in the season. Deep ruts indicate necessity of either sub-drainage or reinforcement of the foundation; an inspection should determine which is the proper remedy. On side hill roads frequently a deep drain in the upper side ditch to intercept the ground water

will be effective; where reinforcement is decided as necessary, usually sub-base construction about eight feet in width will be sufficient. Field stone, quarry spalls, broken stone, slag or gravel are proper materials for such reinforcement.

Frost boils so-called are caused by wet spots in the earth foundation freezing and heaving; later when the frost leaves and the foundation soil is soft the thin macadam crust tends to break through under loaded wheels. These spots which usually occur where the road construction is in a cut, should be excavated, and drained if practicable; any wet clayey soil or silt removed and replaced by gravelly material, field stone, quarry spalls or other good material; the macadam is then replaced.

Ravel is the term applied to describe the condition where the fragments of broken stone become loosened from the body of the road, due to the binding agent failing to perform its function. Bare, toothy or a pitted condition of surface are the varying degrees of a slightly rough surface due to the interstices between the fragments of stone not being filled flush with the binding material or when the wearing surface has innumerable extremely slight depressions. Dust, which is self-explanatory.

The remedy for raveled, pitted or dusty condition is a surface treatment of bituminous material and cover.

These treatments are generally made using a grade of asphaltic residuum oil or a refined tar product which can be applied cold, or which requires very little heating, and better and more uniform results are obtained where a pressure distributor is used. If a pressure machine is used not less than twenty pounds pressure should be required.

Asphaltic base oils, or tar products having a bituminous content of from 40 to 60 per cent. may be applied by gravity sprinkler, but 60 to 75 per cent. asphaltic oils or tars containing 60 to 70 per cent. of pitch are preferably applied by pressure. Uniformity in application is important.

As to the relative merits of asphaltic residuum oils, cut back asphalts, high carbon, or low carbon tars there is a diversity of opinion (see also page 210). Relative cost and durability will naturally be the considerations controlling the selection. The material which is the cheaper at one delivery point may not be at some other. As to the durability it is doubtful if there is any advantage as between the asphalt and tar products. When applied, the tar material appears to take a set faster than the asphalt, which is a decided advantage, but more criticism is made as to slipperiness of the tarred surfaces during freezing weather. It is thought that the tars have the greater adhesive quality, but that the exposed surface due to evaporation of volatile constituents becomes crumbly or dead in a shorter time than a similar grade of asphalt.

Regarding rate of application per unit area, this will vary with the porosity of the surface to be treated; for the cold, or light hot application ranging between one-sixth and one-third gallon per square yard. Experience is that from one-fifth to one-quarter gallon will produce good results on the average surface.

Preliminary to the applying of the bituminous material the surface to be treated should be swept clean if necessary, to free it from all loose and organic matter; after this has been done the application can proceed regardless of whether the surface is wet or dry, providing there are no pools of standing water on the surface, a slightly damp surface apparently gives better penetration than an absolutely dry surface, the object sought being to get the material into the texture of the road. The surface treatment should be confined to one side or half width of the road at a time, leaving the other side available for traffic. Some little time should be allowed for proper penetration, but within one hour after the application it should be lightly covered with suitable material. Traffic can now use this side and the treatment continued on the opposite side.

The materials recommended for cover are crushed stone or slag which will pass a ½-in. mesh and are free from dust; ore tailings, fine screened gravel or coarse sharp sand. The toughness of the mineral aggregate used for oiling cover is an element in the durability of the mat formed by the treatment. Relative cost will determine the selection of material to be used for cover. The quantity of cover necessary will vary with the rate of application of the bituminous material and with the porosity of the surface treated.

Where the rate of application of oil is from one-fifth to one-quarter gallon per square yard the range of cover may be stated as being between 35 and 70 cu. yd. per mile of road 16 ft. wide, and generally 40 to 50 cu. yd. will be ample.

This cover should be uniformly applied either by hand or by mechanical spreader; however, only sufficient to cover the oil lightly should be applied at one time. It will require two or three separate spreadings from time to time as the surface becomes shiny and sticky to produce a perfect mat. Any excess unused material delivered for cover should finally be gathered up and stored in neat piles back of the ditch line where possible. These treatments do not require rolling, although rolling tends to turn any coarse sharp fragments of cover-material onto their broader sides, reducing danger of tire cuts to a minimum.

Thick mats[1] formed of binder and ¾-inch stones while durable are not generally satisfactory; they are expensive, costing from $1000 to $2000 per mile and frequently become rough under traffic, although they do serve at times to carry a road along for a few years which would otherwise be a resurfacing matter. This treatment also is used to restore a crown to a road worn flat.

On gravel and new waterbound macadam and upon roads where there is little motor traffic, maintenance by calcium chloride is effective. Where this treatment is used the applications may be of the granulated crystals applied by hand or by a mechanical spreader, at the rate of 1 lb. to 1¼ lb. per square yard; preliminary sweeping is not necessary unless there is excessive dust say ¼-in. depth or more upon the surface proposed to be treated. Should

[1] The authors wish to emphasize the danger of using thick mats for ordinary maintenance.

this treatment be made immediately preceding a rain, a considerable quantity of material would be lost. Two or three treatments as above should suffice for the average season, and the width treated may be confined to the width of the traveled way. This treatment has cost in New York State about $150 a mile a year. Surfaces which have previously been oiled are not recommended for calcium chloride treatment.

In cases where continued surface treatments of bituminous material through successive years has built up an excessive depth of mat, which has a tendency to be unstable and rut, it is suggested that such mat be removed and spread upon the shoulders, which will cost from $50 to $150 a mile, and that surface treatments be again made upon the macadam itself. Should it be found that the macadam has become uneven, as to crown and grade, or is badly worn or has numerous holes, it is suggested that the road be scarified and thoroughly dragged with a heavy spike-tooth harrow, after which an agricultural weeder should be repeatedly hauled over the road, the object sought being to work all of the finer particles to the bottom of the scarified course, leaving fairly clean coarse stone at the surface; this should be shaped up by hand or scraper and rolled to develop any irregularities in the surface which should be corrected by the addition of new crushed stone. Any pockets of fine material should be removed and replaced by new top course stone, the weeder should again be used to loosen the stone, which will then be ready for the first application of binder, which may be at the rate of three-quarters of a gallon per square yard, application being made by a pressure distributor, the surface then to be covered with a layer of ¾-in. broken stone and thoroughly rolled. During the rolling, additional ¾-in. stone shall be applied and broomed about until the voids in the top course are well filled; all loose stone shall then be swept from the surface and a sealing cost of one-half gallon of binder per square yard shall be applied and immediately covered with a layer of ½-in. stone and again rolled; surface will then be ready for traffic. This treatment is probably better adapted to waterbound macadam than to the penetration bituminous type; however, if found necessary to break up and reshape penetration macadam, it is suggested that the latter loosening by the weeder qe omitted and a spread, one stone thick, of 2-in. broken stone be applied and the first application of binder be increased to one gallon or one and a quarter gallons. This method is not applicabe to an extended mileage as it is generally better to resurface lwhen a road reaches this stage.

Concrete Roads with Thin Bituminous Surfaces.—The second-class concrete with thin bituminous wearing surface is a difficult type to maintain; the bituminous surface under traffic patches off, and as the concrete is usually not strong enough to resist abrasion, holes develop in the concrete; patching results in a rough riding surface and probably the best way to secure a smooth riding road is to resurface, using a 2-in. bituminous mixing type top.

Asphalt, Topeka Mix, Amiesite, Etc.—The holes which develop in the bituminous mixing method type wearing surfaces should be

repaired as follows: Excavate the old material at the defective spot the entire depth of course, so that the edges will present clean, vertical surfaces, these surfaces and the exposed foundation to be swabbed or painted with hot asphaltic cement or paving pitch, the hole then to be filled, with a mixture similar to that used in original construction, whenever practicable, using sufficient quantity so that after consolidation by rolling (or tamping in case the extent of repairs is limited) the surface of the new patch will be flush with the adjacent pavement. In case there is no local mixing plant available, or the limited extent of repairs do not justify expense of treatment as above, holes may be repaired with the mixture of crushed stone and cold patch asphaltic emulsion, as outlined for macadam surfaces.

Concrete Pavements.—The cracks which develop in concrete pavements may be the result of either frost action, settlement of foundation or contraction, and are properly treated by being poured with hot paving pitch or asphalt binder. If spots disintegrate, the defective material should be removed and replaced by new concrete.

Brick Pavements.—Block pavements of brick, stone, asphalt, etc., properly constructed should not require repairing for a considerable term of years; cracks which develop should be grouted with hot paving pitch or asphalt binder; areas which settle, thereby breaking the bond of the grouted joints resulting in crushing or cobbling the blocks, should be taken up, the sand cushion reformed, all sound blocks cleaned and relaid, being turned over where necessary, any broken blocks to be replaced by new whole ones, joints then to be grouted with Portland cement grout preferably, if the original pavement was so constructed, otherwise the joints may be poured with hot paving pitch. It should be noted that repairs with fresh cement grout require to be protected by barricades for a period of about a week, so that such repairs should be confined to one side of the pavement in long stretches, leaving the other side available for traffic; where the repairs are limited in extent and barricades are especially undesirable, the patch may be covered with two inches of earth and further protected by planking during the time required for the grout to set. Where joints are poured with paving pitch, traffic need be diverted only during the time of actually making the repair; this is a decided advantage.

Observation demonstrates that horse traffic on steep grades leave the pavement and seek the earth shoulder, so that so far as practicable these shoulders should be improved by widening, and by graveling or covering with broken stone to avoid excessive rutting, also that on sharp curves the tendency of motor vehicles is to cut close to the inner edge, making it well for this reason to stone or gravel the shoulders at these points.

Along the edges of the rigid types of pavement, block and concrete especially, traffic usually develops a deep rut which if neglected becomes dangerous, to rapidly moving traffic; this rut should be kept filled with gravel or broken stone. Excess material when removed from the shoulders should be so disposed of as to widen embankments and flatten slopes.

General Organization Methods.—There are three general plans for performing the work of general maintenance, the patrol system, the repair gang and by contract. The nature of the work renders it difficult to estimate in terms of labor and material with precision, so that except in the case of surface treatments, repair by contract is not advised. By the patrol system the roads patrolled are under constant supervision and the responsibility for neglect is fixed. The repair gang may be used to supplement the patrol system when it is desired to expedite extensive small repairs, and also to perform all necessary repairs upon any roads not patrolled. A patrolman living in the vicinity of his work, equipped with a single horse, one-yard wagon and small tools, costing $3.00 a day, can make all minor repairs on a section of between 5 and 7 miles of macadam. The repair gang should be equipped with a small motor truck, say of one and a half tons capacity, to be used in transporting the men and tools within a radius of about 25 miles from their headquarters base; this truck can also assist by hauling some material required in the work.

It is concluded that a combination of the patrol and repair gang systems is an improvement over the adoption of either plan of organization exclusively, also that the success of either plan depends entirely upon the experience, good judgment and ability of the man in direct charge and control of this work. As nearly all of the hauling in connection with maintenance work is over hard-surfaced roads, motor equipment for delivering stone, oil, etc., would naturally be considered. The writers' opinion is that for short hauls teams are economical, also that the motor tractor and trailers system of equipment are more efficient than the complete single unit system.

Summarized Costs for the Season of 1915 New York State.—In order that the following figures may be more easily understood, it is well to outline the development of the use of the different types of pavement.

From 1898 when State highway improvement began until 1909 to which time 1787 miles had been constructed, practically the entire mileage consisted of waterbound macadam. Up to this time there had been no systematic maintenance, which resulted in a large mileage of road requiring more than ordinary expenditure to bring it up to standard.

Beginning in 1909, penetration bituminous macadam was generally used on the main roads with brick near cities and villages.

About 1912 the department tried out concrete roads with thin bituminous oil tops. This type proved unsatisfactory in that the bituminous surface peeled in spots and the concrete used was not sufficiently strong to stand the traffic directly. The high cost of maintenance can be seen from the following table. The type has not been used since 1914. The department is now designing first-class concrete roads where roads of that class are economical.

In the following tabulation of maintenance and renewal costs, therefore, the average per mile represents approximately a fair sample of both yearly maintenance and renewal for waterbound

TABLE SHOWING MAINTENANCE AND RENEWAL COSTS IN 1915[1]

Type of Road	Number of Miles	Per Cent. of Total Mileage	Total Cost	Cost per mile Maintenance and Renewal	Cost per mile Ordinary Maintenance	Cost per mile of Renewals Distributed over Total Mileage of Each Type (See Next Table)
Gravel....	193	3	$ 183,921.50	$ 955	$555	$400
Waterbound macadam....	2298	41	2,415,726.84	1051	551	500
Penetration Bit. Mac	2387	43	1,217,059.84	510	410	100
Mixed " "	63	1	11,399 36	181	180	...
Concrete Bit. surface coat....	295	5	309,589.53	1049	500	550
1st class Concrete Pavements..	84	2	10,867 80	129	130	...
Block Pavements....	291	5	55,253.22	190	170	...
Totals and averages....	5611	100	$4,203,818.09	$ 750	$480	...

[1] Costs include all engineering and overhead administrative charges.

macadam, gravel and concrete bituminous and represents only ordinary yearly maintenance for bituminous macadam, concrete pavements, brick and other high-class rigid pavements; none of these latter classes have been down long enough to yet require renewal, which makes their cost as shown much less than will ultimately be required.

Of the mileage shown in the preceding table, the following table shows the amount of resurfacing.

TABLE SHOWING RESURFACING COSTS 1915 [1]

Type of Road Resurfaced	No. Miles	Total Cost	Cost per mile
Gravel	12.88	$ 77,686.27	$ 6,000
Waterbound Macadam	176.29	997,776.66	6,000
Penetration Bituminous	43.72	243,760.22	6,000
Concrete Bituminous top	24.85	160,321.37	6,400
Block Pavements	0.36	4,003.40	12,000
Totals	258.10	$1,483,547.92	

[1] The type of resurfacing is not necessarily the same type as the original road as shown in column No. 1.

Supplementary Explanation of Mr. Bristow's General Costs and Discussion

The authors wish to call attention to two points in the general cost tabulation. The average cost of maintenance and renewal for 1915 is given as $750 per mile for the total system. This system includes approximately 1000 miles of road recently built on which there is practically no charge except minor repair aggregating not over $200 per mile per year. For a completed system of this character all of which is under normal maintenance and renewal, the average cost per mile would be approximately $900 per mile, as is evident by excluding the thousand miles from the tabulation of total cost.

In the resurfacing table it is evident from the cost per mile that better grades of top courses were generally placed on the waterbound and gravel roads than originally constructed; this means that in some cases the original design was not proper for the class of traffic the road served.

The most evident faults of the usual maintenance are in delaying the work till late in the season and in careless mending of ruts and depressions before the application of surface treatments. It is well to emphasize the necessity of using a coarse grade of stone preferably 1½″ to 2½″ size in mending noticeable depressions. The hole should be dug out, the edges squared up, the depression

filled, bound with heavy binder and screened and rolled. Carelessness in this regard has resulted in a large amount of justifiable complaint. The following quotation from the 1917 report of Mr. Fred Sarr, 2d Deputy Highway Commissioner of New York State is very reliable and up to date data as the bookkeeping on which it is based is of a high order.

"The cost of maintenance, repair and reconstruction of a large mileage has been segregated and charged against the roads of various types of improvement, following the plan of the last two years in order to determine the cost of maintenance of the several types of pavements which have been used in the improvement of the New York State and county highways, and the results are indicated in the following tables.

"The pavements are arranged in two groups. In the first group are the types represented by at least 100 miles, or those that by reason of the large mileage and wide distribution should represent with a reasonable degree of accuracy the average cost of maintenance of pavements of the particular typed. In the second group are the types represented by less than 100 miles and too much weight should not be given to the tabulated costs of maintenance of such mileage, in that the results of one year with a small mileage do not fairly represent the actual average cost per mile of maintenance of the particular type.

First Group

Type of Improved Surface	Miles of Improved Highways of Each Type	Expenditures per Mile during 1917 for Maintenance and Repair, Exclusive of Reconstruction to Different Type	Total Expenditures per Mile during 1917, Including Reconstruction to a more Permanent Type of Surface
Bituminous macadam, penetration method, asphalt binder.. . .	2,793.77	$412.00	504.00
Waterbound macadam .	2,534.34	970.00	1,154.00
Brick pavements....... .	280.11	222.00	——
Concrete:			
First Class...	257 46	112.00	——
Second Class........	226.48	1,127.00	——
Gravel	167 72	918 00	1,443.00
Bituminous macadam, penetration method, tar binder....	164.34	352.00	——

"An expenditure of $34,392 which was required to restore to normal condition sections of improved highways that were damaged by cloudbursts and floods, has not been distributed to the particular type of pavement involved, in that the type of construction had no bearing upon this extraordinary expense.

SECOND GROUP

Type of Improved Surface	Miles of Improved Highways of Each Type	Expenditures per Mile during 1917 for Maintenance and Repair, Exclusive of Reconstruction to Different Type	Total Expenditures per Mile during 1917, Including Reconstruction to a more Permanent Type of Surface
Block pavements:			
Asphalt, concrete base...	13 55	$240 00	——
Asphalt macadam base.	2.52	163.00	——
Wood	0 24	——	
Stone................	2.93	30 00	——
Brick cubes, macadam base............. ..	0 33	76.00	——
Concrete:			
Hassam.	58.52	619.00	——
Bituminous Macadam:			
Mixing Method:			
Amiesite, concrete base.	3 73	32.00	——
Amiesite, macadam base,	4 33	1,131.00	——
Topeka, concrete base...	33 74	245.00	——
Topeka, macadam base .	12.64	393.00	——
Open mixed, concrete base	13.32	29 00	——
Open mixed, macadam base	3.58	109.00	——
Bitulithic, concrete base,	13.63	216.00	——
Henderson, macadam base..................	1.11	1,380.00	$9,811.00
Sheet asphalt, concrete base..............	1.22	——	——
Gravel mixed, gravel base............. ...	11.47	738.00	——
Penetration Method:			
Asphalt binder, concrete base..	4 80	174.00	——
Sub-base, bituminous..	14.39	1,079.00	——
Kentucky rock asphalt. ..	17 55	387.00	——
Rocmac.............. .	1.39	3,884.00	——
Total all types.......	6,639 21	$643.00	$767.00

"The cost of maintenance having been segregated and charged against the various types of pavement for the past three years, in order to secure a more reliable comparison of maintenance costs, the experience of the three years has been combined for the types having a material mileage in our system of improved highways with the following results:

Type	Average of the Past Three Years Experience	
	Average Mileage Maintained	Average Expenditure per Mile-year
Bituminous penetration method	2,659	$464.00
Waterbound macadam.......	2,408	976.00
Gravel....................	178	824.00
Brick pavement.............	280	196.00
First Class concrete..........	164	124.00
Second Class concrete........	253	1,082.00
All types...............	6,099	678.00

General

"Efficient maintenance of macadam pavements, particularly of the water bound type, of which there are 2535 miles in the State system of improved highways, necessitates frequent surface treatments with bituminous materials or constant patching of the holes that rapidly develop under the present day motor vehicle traffic.

"Frequent surface treatments are objectionable not only from a traffic standpoint, but from the fact that such treatments tend to build up an unstable mat of bituminous material and mineral aggregate on the surface of the pavement that is displaced by the fast moving motor vehicle traffic, and develops a rough and uneven surface.

"It has, accordingly, been the policy of this Bureau to restrict the use of surface treatments and wear the surface mat down as this is possible before giving another general surface treatment.

"This method, while tending to provide a smoother surface, requires constant patching during the latter stages of the wearing down process.

"Much time and thought have been given to the study of the results obtained by various methods of manipulation and materials used in patching macadam surfaces.

"In making these patches to pavements carrying any considerable amount of motor vehicle traffic, it is necessary to bind the mineral aggregate with some form of bituminous material.

"Light asphaltic oils and refined tar products, similar to those used for surface treatments, have been used extensively for light, thin patches, painting the area to be patched with the bituminous material and covering with stone chips or sand.

"Heavy binders that require heating have been used in the same manner.

"The most satisfactory results have been obtained, where the required patch must be one-half inch or more in depth, by mixing the mineral aggregate with a heavy asphalt or tar binder, cut back with light voltaic oils to a consistency that will mix readily with the mineral aggregate when cold, also with an emulsified asphalt binder used in the same manner.

"The bituminous material and stone aggregate, being mixed either by hand or in a small concrete mixer, permits of a proper proportioning of the materials which has been demonstrated to be about 6 % in weight of solid bitumen or mineral aggregate used, or about one gallon of the cut back or emulsion per cubic foot of crushed stone.

"With asphalt cut back the best results have been obtained by using a material made from an asphalt binder, having a penetration of about 165, cut back with about 33 % in weight of naphtha.

"With tar cut back the best results have been obtained with a material made from a refined tar binder having a melting point of about 70°C., cut back with about 40 % in weight of tar oils, of which at least 60 % shall distil up to 235°C.

"A very satisfactory material for patching purposes is an emulsified asphalt containing about 65% of asphalt binder having a penetration of about 165.

"This material may be diluted with water if desired, and may be mixed with wet mineral aggregate when found in that condition. It readily separates from the emulsified state when combined with crushed stone in the so-called open mix.

"The resultant adhesive qualified of an emulsified asphalt appear to be better than can be obtained by the same asphalt in any other form.

"The only tangible reason advanced for this result is that the water in the emulsion may carry the binder into the pores of the material or pavement to which it is applied.

"The patch made with emulsified asphalt hardens to a condition of stability much quicker than one made with cold oils or tars or cut back binder that we have used, and is, for this reason, preferable to those materials for patching work on heavy traffic highways.

"Very good results have been obtained with the cut back tar cold patch material, particularly on medium to light traffic highways, where the patching material is not thrown about by traffic to any great extent.

"In order to obtain efficient results in patching with a tar binder, it is necessary to make a so-called close mix, by using a graded mineral aggregate having a minimum amount of voids, which, however, will not permit the volatile oils to evaporate as fast and the patch to become stable as quickly as may be obtained with asphalt emulsion when used in the open mix. It is, accordingly preferable when using tar, to mix same with the mineral aggregate and leave in shallow piles for about two days before applying to the road surface.

"The necessity for using the close mix with tar binders, is due to the fact that tar products are more susceptible to the heat and cold than asphalts.

"In other words, if starting with the two materials of the same consistency at 60°F. and the temperature is raised to that of a pavement on a hot summer day, say 130°F., the tar is much more fluid than the asphalt and tends to flow away from the open mineral aggregate, and the open patch will show a tendency to ravel. Again when the temperature is reduced to that of a pavement on a winter day, the tar becomes much more brittle than the asphalts and again the open patch with tar binder is more liable to ravel out than one made with asphalt binder.

"A comparison of the result obtained with the two materials each of which contains a quantity of the semi-volatile oils sufficient to permit them to be applied to the surface of the pavement at 60°F. as a surface treatment, demonstrates that the tar, by reason of its greater fluidity on a hot summer day, will penetrate the old pavement to a greater extent than the asphalts, and thereby serves more as a binder to the old pavement. It is for this reason that cold tars are generally used as the first and second treatment of a waterbound macadam pavement, subsequent treatments of heavy asphaltic oils carrying about 65% of solid bitumen, will give more efficient and lasting results if used conservatively, that is, if the successive treatments do not follow each other too closely.

"When successive treatments are given every year as a dust layer or to obviate the necessity for patching, cold tar is preferable in that it does not build up a mat on the surface of the pavement to the extent obtained with asphaltic oils.

"Providing a mat is built up with successive tar treatments, the same will generally lie flat and not shove under traffic, and develop a wavy and corrugated surface as is often obtained with too frequent surface treatments with asphaltic oils.

"This resulting difference is due to the aforesaid difference in consistency at summer temperatures of the pavements.

"The tar being so fluid at summer temperature, it appears to retain a smooth surface by the effect of gravity, while the asphalt simply softens sufficiently to permit the surface mat to be displaced by traffic, which displacement increased from day to day and often necessitates the entire removal of the old mat.

"Another factor to be considered in deciding upon the material to be used for the surface treatment is the condition of the old pavement.

"Where the old macadam is composed largely of small particles of crushed rock and dust, and is in a more or less loosened condition, and is subject to displacement by traffic, a light asphaltic oil is preferable to cold tar for

surface treatments. The asphaltic oil treatment develops into a mat or carpet over the macadam which remains more or less plastic, even at low temperatures, and displacement of the macadam under traffic does not result in the shattering and the ultimate destruction of the mat to the extent obtained under similar conditions with tar treatments.

"Also for the same reason, asphaltic oils give the best results on pavements where steel shod traffic predominates.

"The best results obtained with tar treatments are where the old macadam pavement is clean or free from dust and where the pavement is firm and sound, and the stone fragments do not displace under traffic, and where motor vehicle traffic predominates, also where a minimum amount of cover material is used in conjunction with bituminous material.

"Macadam pavements surface treated with tar are, however, much more slippery for horse traffic in cold weather than those treated with asphaltic oils.

"In my report of a year ago, I discussed to some length the subject of the extensive breaking through of many of the pavements during the spring months.

"Referring to such report it will be noted that the total area actually broken during the spring of 1916 was equivalent to 82 miles of pavements 16 feet wide, and that the broken areas were distributed over many projects aggregating to a total of 1939 miles, of which an average of 4.2% was broken through.

"During the season of 1916, about 75% of the total broken areas were substantially repaired, and about 238 miles of the weaker pavements were resurfaced.

"The spring of 1917 appeared to be a repetition of the previous year as to the amount of broken pavements.

"The result of a survey to determine the extent of the broken pavements when tabulated indicates that the total broken areas were, however, but 60% of the total of the previous year.

"The total length of the various projects involved aggregating 2090 miles about 9% larger than those reported in the previous year. Of this total length the equivalent of about 48 miles of pavement 16 feet wide was broken up or about 2½% of the total length involved."

Snow Removal.—On main roads between large cities snow removal in winter has become part of the regular program. In many districts automobile trucking relieves rail congestion and is needed even more in winter than in summer. The Maintenance Departments are in a position to handle this work with their organized forces and equipment which are idle at this time of year and the necessary expense is certainly worth while to make the main roads passable for trucks the year round.

Typical Maintenance Costs of Different Types.—From a detailed study of 600 miles of road in Western New York with which we are personally familiar, the following typical costs are derived.

It is assumed that the type used is suitable for the class of traffic served as indicated on page 164.

The maintenance system is a combination of patrol, gang work and contract. A one man patrol with horse and wagon is used to keep the shoulders in shape, the ditches and culverts clean and small holes in the pavement repaired. Gang work with proper machinery under State control to paint guard rail and make more extensive surface repairs and contract work for oiling and surfacing. Detail oiling costs are given under cost data (page 653). This system is not highly efficient as the executive heads are changed at short intervals for partisan reasons; the department is a convenient means of dispensing minor patronage and the maintenance money is rarely available early enough in the spring to be used to

advantage, but it represents about as good a method as can be expected in doing public work on a large scale and as such is of more practical value as a guide of costs than figures based on maximum efficiency.

Patrol Work Macadam Roads.

Regular patrol labor	$70 per mile per year
Extra labor	40 " " " "
Maintenance material	45 " " " "
Guard rail, incidentals, etc	20 " " " "
Total per mile per year	$175 " " " "

Say $200 for waterbound roads
Say $150 for bituminous penetration roads.

Patrol Work Rigid Pavements.

Regular patrol labor	$30 per mile per year
Extra labor	15 " " " "
Shoulder material, etc	30 " " " "
Guard rail, incidentals, etc	20 " " " "
Total per mile per year	$95
Say	$100

15' Waterbound Macadam, Class II and IV Traffic.

Life of top course 4 to 12 years. Say 7 years Class II and 9 years Class IV.

Class II Traffic.

Yearly patrol including materials for minor repairs and painting guard rail at $200 per mile per year	$1400.00
Calcium chloride, 1st and 8th years @ $125 per mile per year	250.00
Cold oiling, 2d year	200.00
" " 3d "	200.00
" " 5th "	250.00
Hot oiling 6th "	1000.00
Cold oiling 7th "	250.00
Resurfacing with waterbound macadam 8th year	4000.00
Eight year total	$7550.00
Cost maintenance and renewal per mile per year	950.00
Cost of ordinary maintenance per mile per year	450.00

Class IV Traffic.

10 years total approx	$8000.00
Cost of maintenance and renewal per mile per year	800.00
Cost of ordinary maintenance	400.00

15′ Penetration Bituminous Macadam Class II and IV Traffic.
Life of top course 6 to 12 years. Say 10 year average.

Yearly patrol @ $150 per mile per year	$1,500.00
Cold oil 3d year	200.00
" " 5th "	250.00
" " 7th "	300.00
Hot " 9th "	1,000.00
Cold " 10th "	250.00
Resurfacing 11th year with bituminous macadam	6,000.00
11 year total	$9,500.00
Cost maintenance and renewal per mile per year	900.00
Cost ordinary maintenance	350.00

18′ Cement Concrete Pavement Class I and II.

Class I Traffic (12 year life).

Yearly patrol and incidentals @ $150	$1,800.00
Resurfacing the 13th year with either asphalt, brick, clay cubes or rebuilding with concrete @ $10,000 to $16,000 per mile	14,000.00
13 year total	$15,800.00
Cost maintenance and renewal per mile per year	1,220.00
Cost ordinary maintenance	150.00

Class II Traffic (15 year period).

Yearly patrol and incidentals	$ 1,500.00
Resurfacing	13,000.00
16 year total	14,500.00
Cost of maintenance and renewal per mile per year	$ 900.00
Cost of ordinary maintenance	100.00

18′ Brick Pavement Class I Traffic
Probable life 15 years based on reports from 80 cities.
Range of life 10 to 25 years.

Yearly patrol and incidentals	$ 2,250.00
Replacing brick surface	18,000.00
16 year total	$20,250.00
Cost of maintenance and renewal per year	$ 1,250.00
Cost ordinary maintenance	150.00

Maintenance Conclusion.—The indications are that the yearly cost of maintenance and renewal of a well designed high-class road system will run about $900 per mile per year. The effect of bad design is evident from resurfacing costs, for if waterbound macadam is built on a Class I traffic road the life is easily halved, increasing the maintenance and renewal cost to $1500 per mile per year and causing continual inconvenience to the traveling public by repairs and reconstruction.

Probably the most feasible method of reducing maintenance cost will be the utilizing prison labor to manufacture and in a limited way apply the maintenance materials.

CHAPTER VIII

MINOR POINTS

Under this heading are included right-of-way widths, guard rail, bridge rail, snow fences, retaining walls, toe walls, curbs, guide and danger signs, cobble gutters; rip rap, catch basins, grates, dykes, storm sewers; flow of water in ditches and cattle guards.

Right-of-way Widths.—Many of the older communities are handicapped in road improvement by narrow right-of-ways which require widening at a large expense and considerable legal difficulty. Where right-of-way is acquired for new locations future development should be considered. The width acquired must be sufficient to include all cut and fill slopes. Where these considerations do not increase the normal width the following normal widths are recommended:

Mountainous regions (cheap land)	100 ft.
Farming country (moderately cheap land)	80 ft.
Thickly settled districts (expensive land)	60 ft.

Clearing Widths.—Clearing of trees, brush, etc., depends on height and thickness of growth; the object of clearing is first to

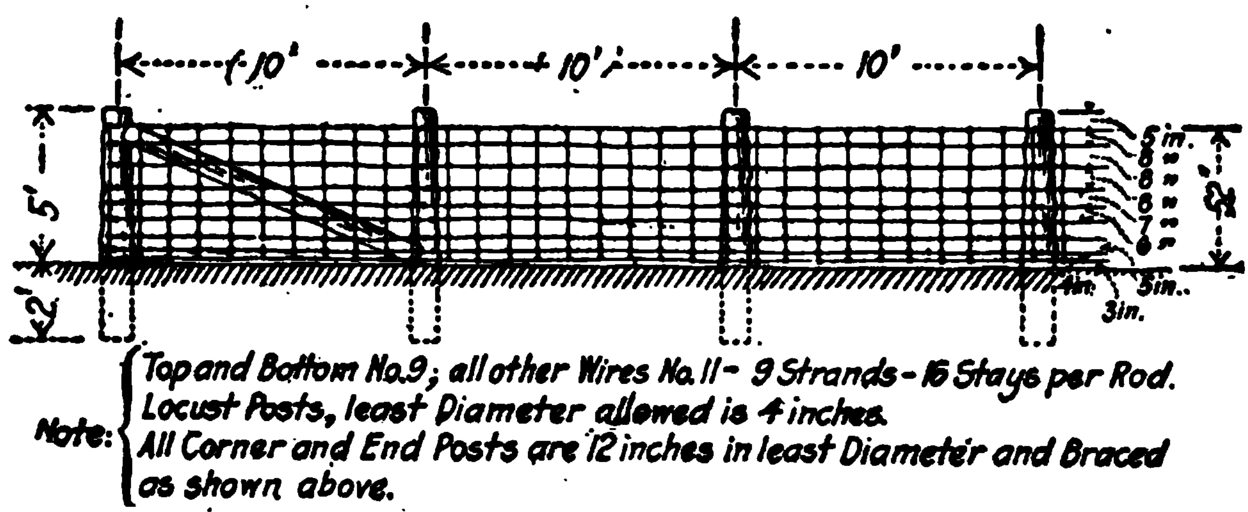


FIG. 42.—Right-of-way fence.

remove growth within the slope lines, second to provide a clear view and third to clear sufficient width to allow the sun to reach the road and dry it out and melt snow. This last depends a good deal on the direction in which the road is running and the altitude and geographical location. It is entirely a matter of judgment but should be liberal in the forest districts and ranges from 30 ft. for low scrub growth to 150 ft. in adverse location and thick

high growth. In high altitudes the roads are at their best closed in winter and if careful location and liberal clearing will increase the length of open season it is well worth while as in effect it increases the usefulness of the road by 15% to 25%.

Guard Rail

Wooden Guard Rail.—The construction generally used is shown in the following sketch.

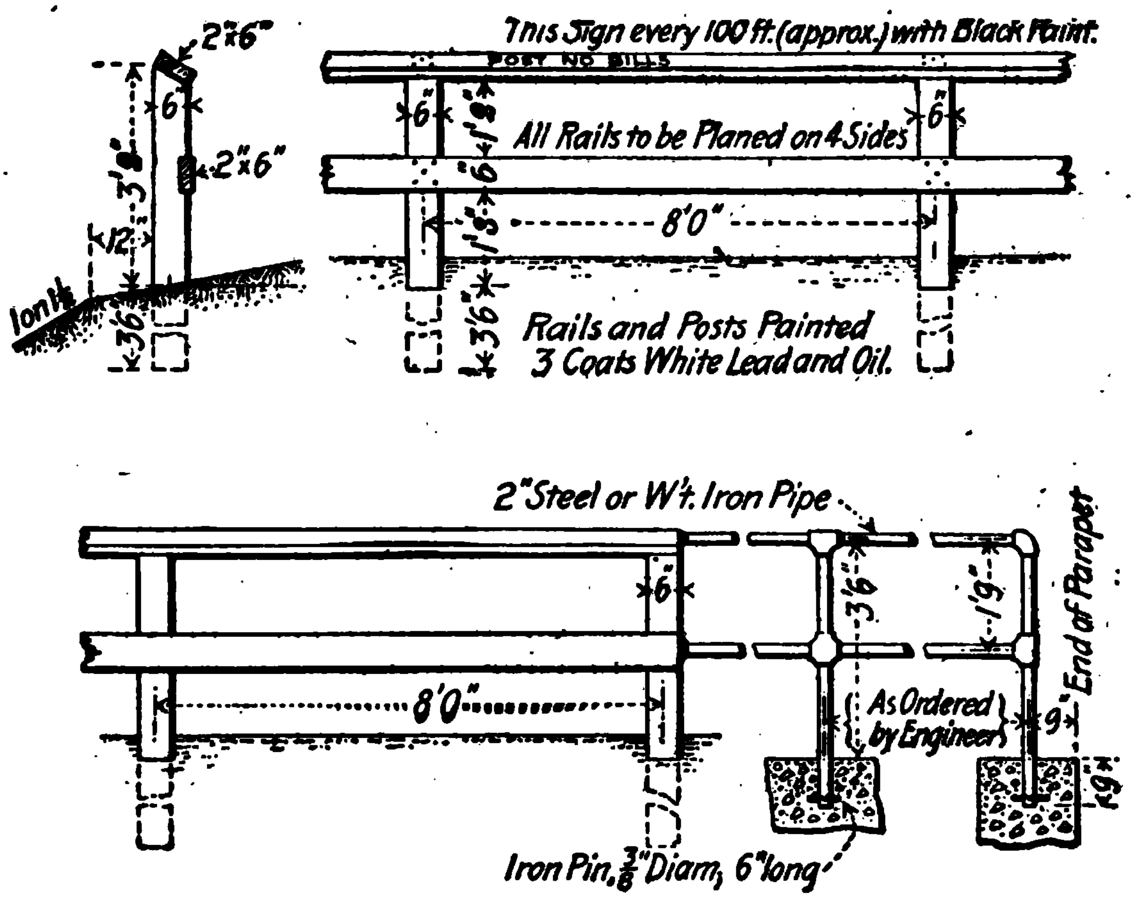


FIG. 43.

The posts are cedar, white oak, or chestnut, and the rails are hemlock, yellow pine, or white pine. Such guard rail costs from 25c. to 40c. per foot, about 5c. per foot per year for maintenance, and needs renewal every 8 to 10 years; the capitalized cost at 4% is approximately $1.25 as figured by the New York State Highway Commission, and on this basis they have decided that it is cheaper to use a fill slope of 1 on 4 up to a seven foot depth eliminating the guard rail than it is to use a 1 on 1½ fill slope with guard rail.

The wooden guard rail as built acts as a warning only. If a machine or rig becomes unmanageable and hits the rail, it generally breaks or the posts tear out, allowing the vehicle to turn turtle on the fill slope. So many accidents of this kind occur that there is a demand for a rail that actually gives protection as well as a warning.

Concrete Guard Rail.—Because of this demand and the high cost of maintenance and renewal of the common wooden rail, concrete guard rail is being adopted. The simplest and best

design of this kind that the author has seen was tried out by the New York State Department of Highways on the Ridge Road, near Rochester, N. Y. in 1910. A sketch is given below. This construction has been specially commended by the automobile associations (Fig. 44).

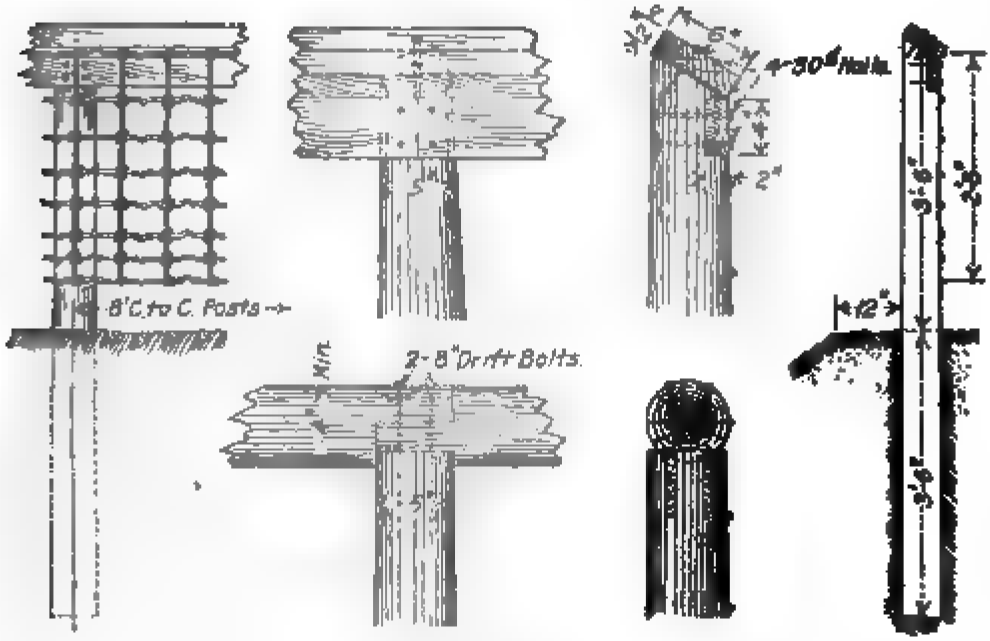


FIG. 43A.—Minnesota guard rail.

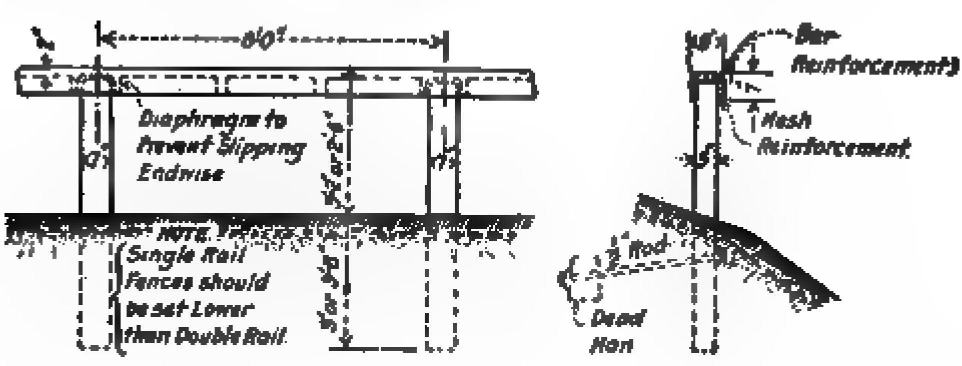


FIG. 44.—Concrete guard rail.

The rail was invented by J. Y. McClintock, County Engineer of Monroe County, N. Y. It is neat in appearance, durable and strong, and is specially adapted for a combination bridge and approach rail. The old design of an iron bridge rail connected with a wooden road rail has been an eyesore.

The actual cost of manufacture and setting was from 50 to 60c. per foot. The contract price for such rail would, probably, run from 80c. to $1.00, depending upon the length of the haul, freight rate, and difficulty of digging post holes but even at the high figure it is cheaper in the end than wooden rail and is a

safe construction. The anchor and rod shown on the sketch is used on curves or even on straight stretches where new fill is encountered, to prevent the posts being torn out by impact from runaway machines.

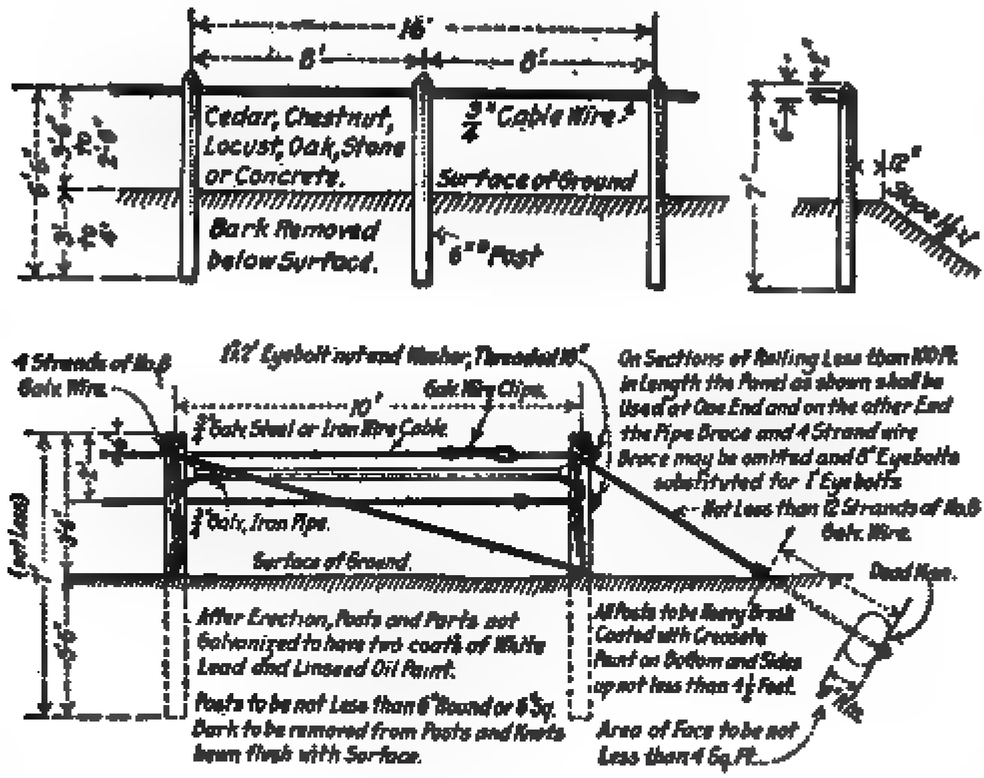


FIG. 45.—Cable guard rail.

The rail proper has a web and bar reinforcement; it is designed to stand a 6 ton horizontal load at the center of the panel. The rails and posts are molded separately and allowed to set for, at

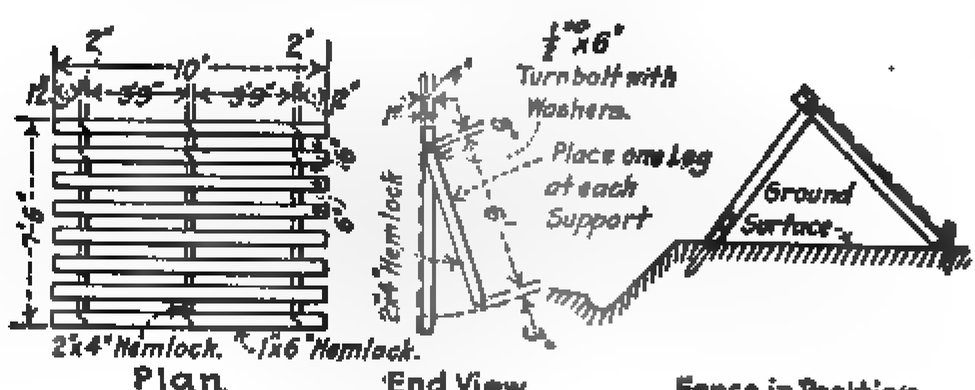


FIG. 46.—Snow fence.

least, a month; they are then put together in much the same manner as the wooden rail. The rounded top of the post makes it possible to erect on any grade.

A considerable mileage of this rail has been erected in New York and New Jersey and has prevented many serious accidents. It has been hit by autos, tar kettles, rollers, traction engines and rigs and in no case has the vehicle gone over the bank—which is the general cause of fatal accidents. The rails and posts will break when hit by a heavy machine, but the reinforcement merely bends (does not snap) and continues to exert enough resistance to hold the machine on the roadway.

Guard rail has two distinct purposes; first as merely a warning, at culverts, curves, low embankments, etc., where the danger is not great and second, as an actual protection in dangerous places.

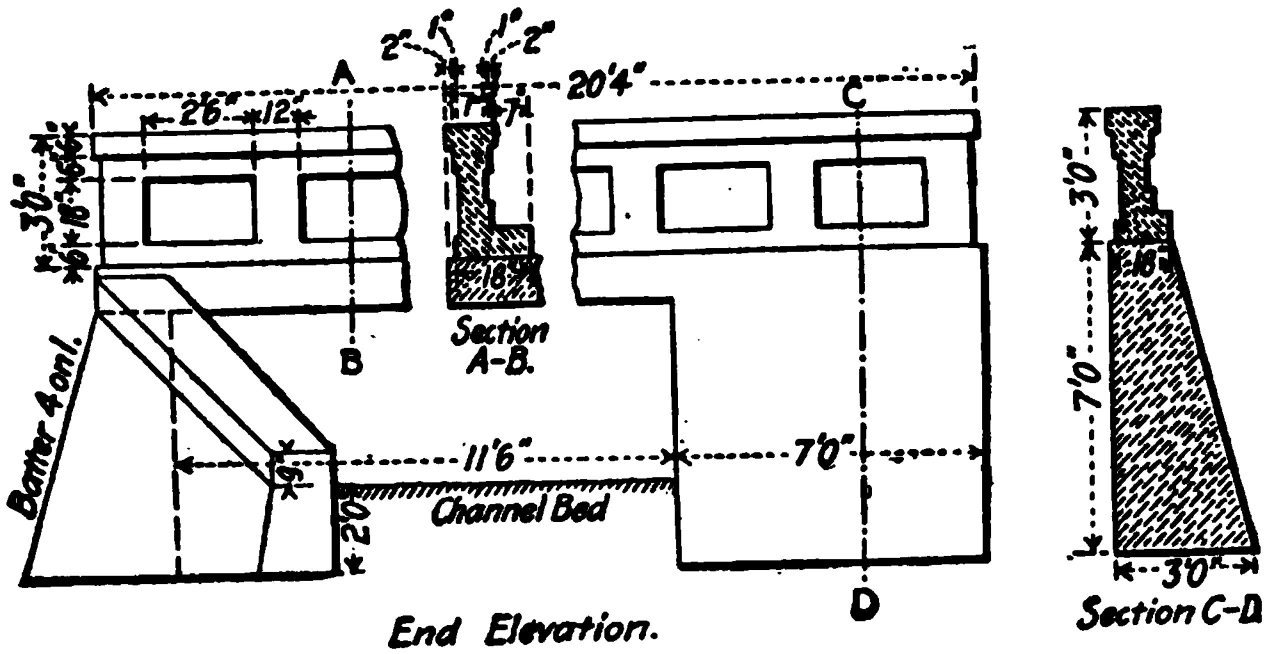


FIG. 47.—Showing raised parapet on skew bridge extended over straight parapet retaining wall.

Concrete guard rail is not advocated where warning alone is sufficient.

Wire Cable Guard Fence.—Figure 45 illustrates this construction.

Snow Fences.—Sketch No. 46 shows a typical snow fence used to prevent drifting in bad locations.

Bridge Rail and Raised Parapets.—Bridge rail for small span bridges is of two types, iron pipe rail (see Figure 43) or solid raised parapets (see Figure 47). The solid parapet is to be preferred.

Retaining Walls.—In unusual cases retaining walls are needed in road construction. Plain or reinforced concrete walls are generally used, the selection depending upon the relative cost. The plain concrete wall is considered the best type for heights up to 12 ft.; the reinforced cantilever form from 12 to 18 ft. and above 18 ft. the buttressed design. We give, page 220, examples and rules for the plain and reinforced cantilever types only, as the necessity for walls higher than 18 ft. is very rare. For the design of buttressed walls the reader is referred to the standard works of reinforced concrete.

Retaining walls are usually built in monolithic sections of 20′ to 25′ in length; expansion joints are provided between these sections. The expansion joints may consist of simply a plane of weakness between the sections produced by allowing one section to set

before building the adjacent wall, or it may be a key joint as shown in Figure 49A and the plane of separation may be made more pronounced by coating the concrete with a thin layer of asphaltum or pitch.

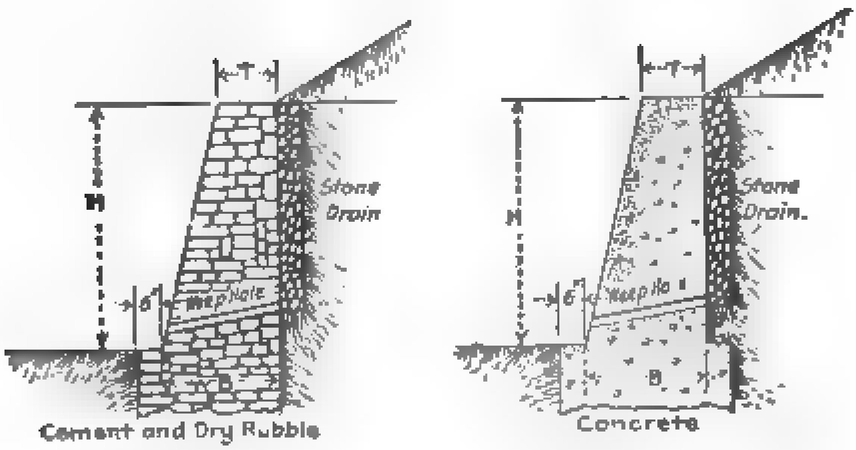


FIG. 49.—State of Pennsylvania retaining walls.

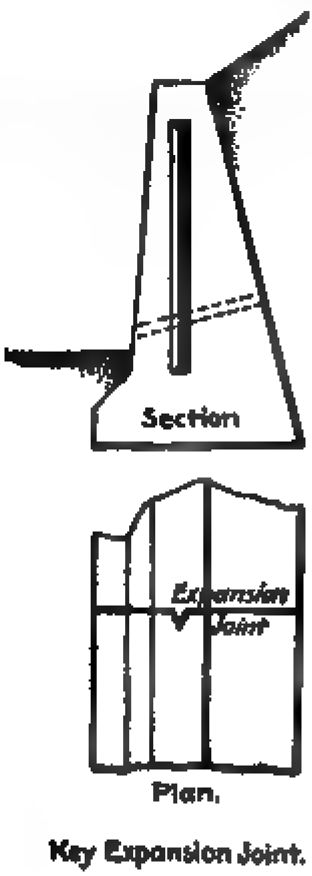


FIG. 49A.

Toe Walls.—Toe walls are nothing more than low retaining walls or very substantial curbs. They are used in cuts on the outside of the gutters to prevent unstable side slopes from filling the gutters or heaving them out of shape by sliding pressure. Figure

50 gives a section of Eden Valley Hill near Buffalo, N. Y. where a clay quicksand cut was successfully protected in this manner.

Curbs.—Curbs are constructed of stone and of concrete..

Stone Curbs.—The cuts given show the methods of setting; the size of curbstones for first-class work range from 16″ to 22″ in depth, 5″ to 6″ in thickness and 3′ to 5′ in length. For small villages, curbstone of 4″ width set in the simplest manner shown,

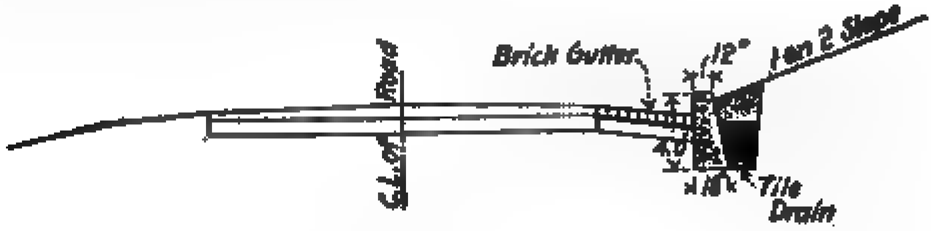


FIG. 50.—Showing concrete toe wall.

is satisfactory. The stones most used are granites, bluestones of New York State, and the tougher sandstones such as Medina, Berea, Kettle River, etc. The prices range widely, depending on the locality of the work. Mr. William Pierson Judson, in his "Roads and Pavements," gives the following range of costs:

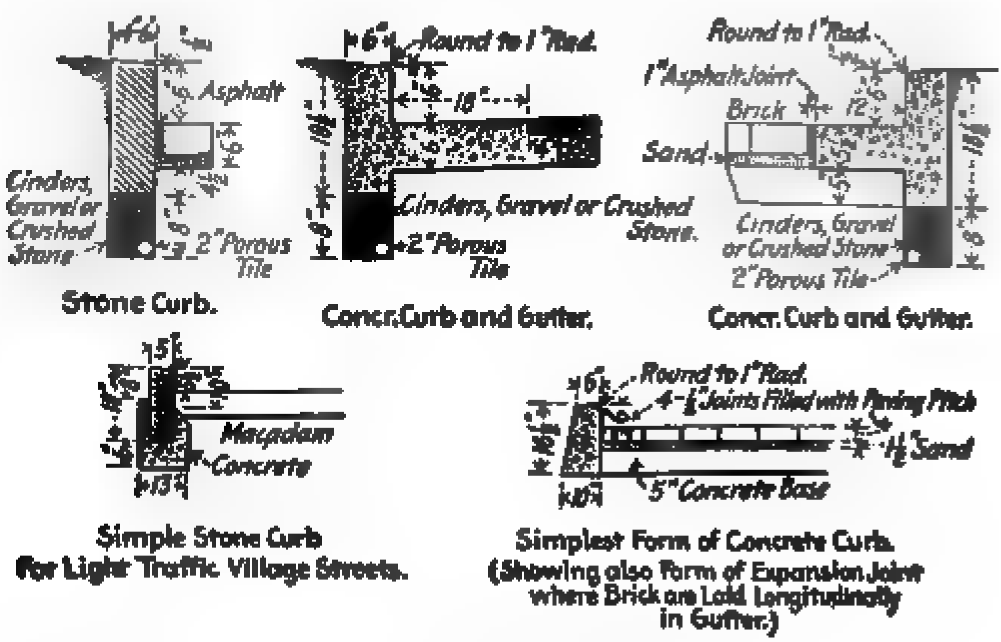


FIG. 51.

Straight curbs set, cost about as follows: with 30% to 50% added for curves; granite, $0.50 to $0.90, unusual case $1.25 per foot.

Ulster and Oxford bluestone, $0.40 to $0.80, unusual case $1.00 per foot.

Medina and Berea sandstone, $0.35 to $0.90.

Concrete usually costs from $0.40 to $0.50 with $0.35 added for a combined gutter, though combined gutter and curb have been built for $0.50.

Simple concrete curb (Figure No. 51) has been built during 1911 in different parts of Western New York at a cost of $0.30 to $0.40 per foot.

Where stone curbs can be built for less than $0.70 per foot, it seems good policy to use them through the business sections of small villages. For the residential portions or where the cost of stone curbing is high, a concrete curb of the simplest design is the best practice, as city conditions and requirements are neither necessary nor expected.

Curb Radii.—A good radius for drives is 4 ft. For right angle Main Street intersections 13 ft. For acute or obtuse angles 10 to 20 ft.

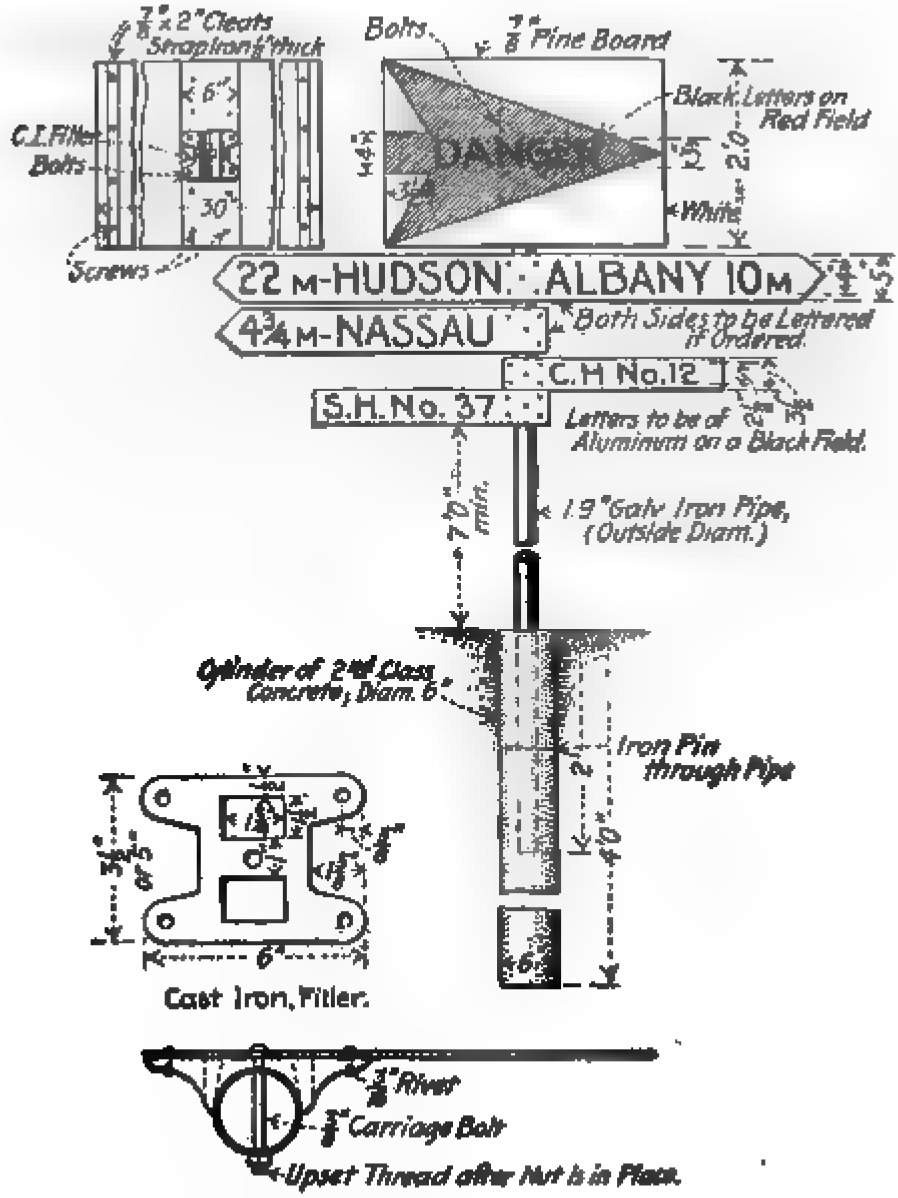


FIG. 52.

Guide Signs and Danger Signs.—A good sign must be easy to read, pleasing in appearance and permanent. The drawing (Figure 52) shows one of the designs in use; the posts are of galvanized iron and cost about $5.00 in place; the background for the aluminum is a japanned metal; the signs cost approximately $0.15 per

letter including the board. Danger signs should be used only where no doubt exists as to their necessity, as their indiscriminate use decreases their effectiveness.

Riprap and Dykes.—Well constructed riprap protects stream banks and bridge approaches from stream wash except in unusual cases where a solid masonry or concrete protection is required.

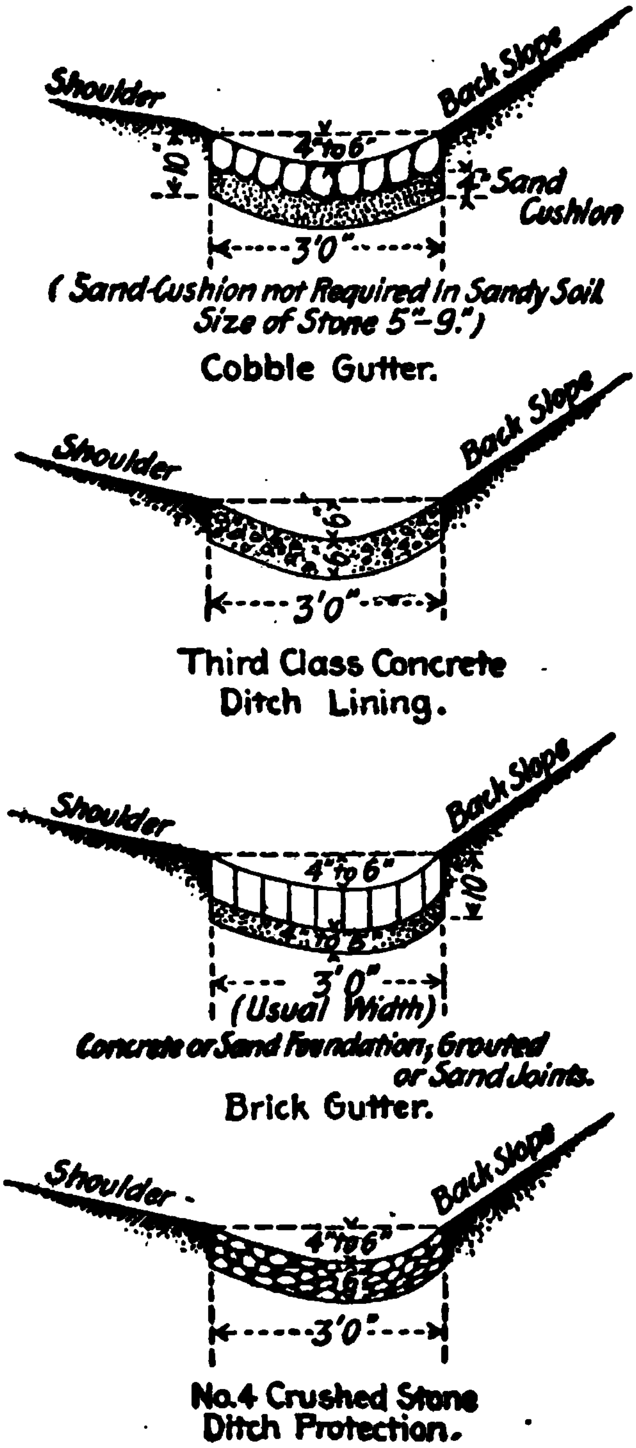


FIG. 53.

The sizes of stone suitable for riprap are usually specified at a minimum of ½ cubic foot and 50% or more of the material to be over 2 cubic feet.

Where the road is located in bottom land and is covered with backwater in the Spring, it can be protected by riprap paving on both sides or a dyke and riprap paving on one side as shown in Figures No. 55 and No. 56.

Cobble Gutters, Brick Gutters, Ditch Linings, Etc.

Cobble gutters are used to protect the ditches from wash on steep grades and at entrances to intersecting roads where there is not sufficient headroom for a culvert.

Also at the entrances to private property where the grade line of the ditch might be badly cut by vehicles.

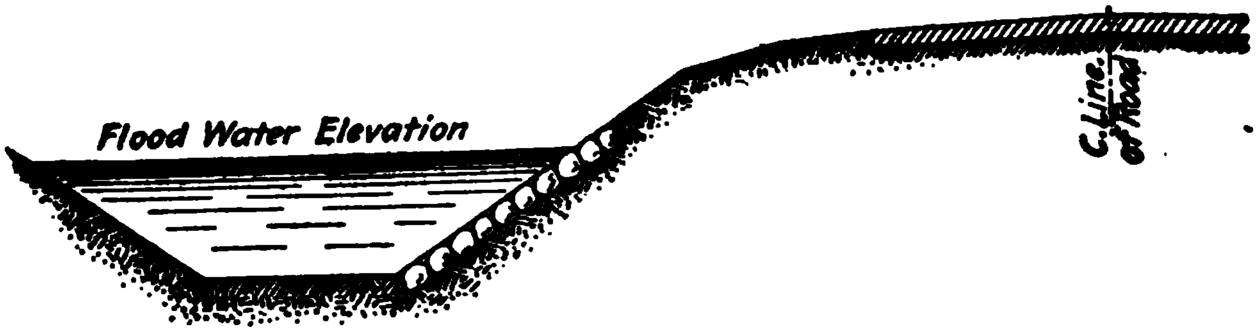


FIG. 54.

The usual cost of such construction ranges from $0.40 to $1.00 per square yard.

Where cobblestones are not available, ordinary building brick may be used or No. 4 crushed stone as shown on page 225.

FIG. 55.—Method of protection where road can be built above flood level.

Grates.—Cost of cast-iron grates about $0.065 per pound.

Cost of wrought-iron grates about $0.08 per pound.

Repointing Masonry and Refacing Old Walls.—Old masonry structures can often be used complete or in part by repointing the

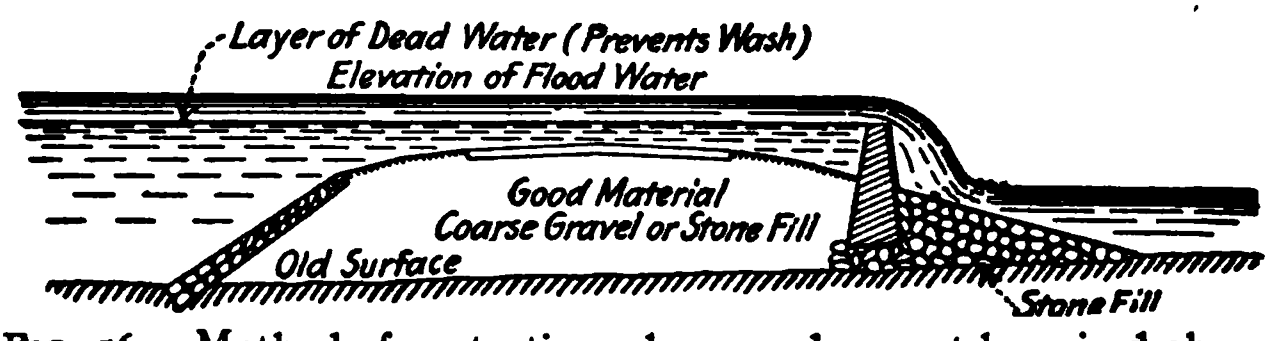


FIG. 56.—Method of protection where road cannot be raised above flood level.

joints; they should be cleaned out thoroughly with a chisel and filled flush with a 1 to 1 Portland cement mortar.

The author does not believe in facing up old masonry abutments if it can be avoided; however, if it seems advisable, because of shortage of funds, the old joints should be well cleaned out and

hook dowels used as shown in cut No. 58. One dowel every 6 sq. ft. is good practice.

The concrete facing should be at least 12 in. thick, have a good footing course and be reinforced to prevent settlement and temperature cracks.

Storm Sewers on Hills.—For the convenience of designers the approximate flow capacity of ordinary sized pipes on different grades are given below in Table 23.

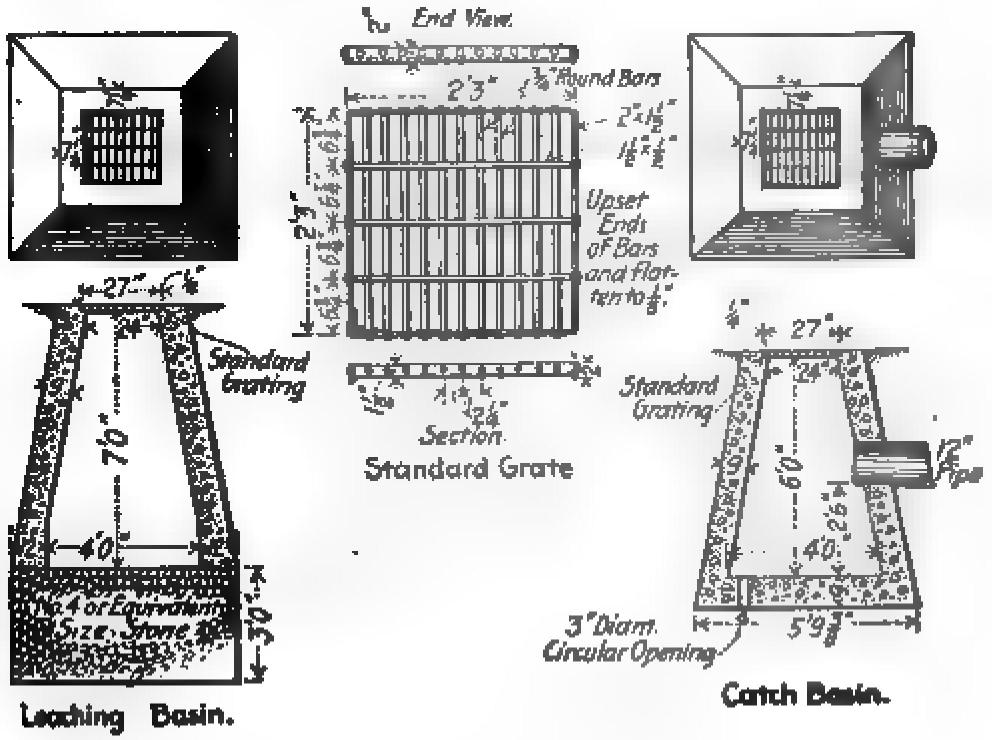


Fig. 57.

Table No. 23.[1]—Approximate Flow Capacity in Cubic Feet Per Second

Value of N = 0.013

Grade	Capacity of Flow of Different Sized Pipe					
	12"	15"	18"	20"	24"	36"
0.5%	2.4	4.4	7.5	9.5	16.0	42.0
1.0	3.3	6.3	10.5	14.0	23.0	60.0
1.5	4.2	7.6	13.0	17.0	27.0	75.0
2.0	4.8	8.8	15.0	19.0	31.0	86.0
3.0	5.8	11.0	18.0	24.0	39.0	105.0
4.0	6.5	13.0	22.0	27.0	46.0	122.0
5.0	7.3	14.0	24.0	30.0	51.0	137.0
6.0	8.1	15.0	26.0	33.0	56.0	150.0
7.0	8.8	16.0	27.0	35.0	60.0	162.0
8.0	9.5	17.0	28.0	38.0	65.0	173.0

[1] Computed from diagram Ogden's Sewer Design.

Flow of Water in Ditches.—Multiply area of flow by velocity. Velocity can be roughly approximated by the formula

$$V = C\sqrt{RS}$$

V = velocity in feet per second
C = constant = 60 for ordinary cases
R = hydraulic radius = $\dfrac{\text{cross-sectional area of flow in sq. ft.}}{\text{wetted perimeter in lin. ft.}}$
S = slope of stream per foot.

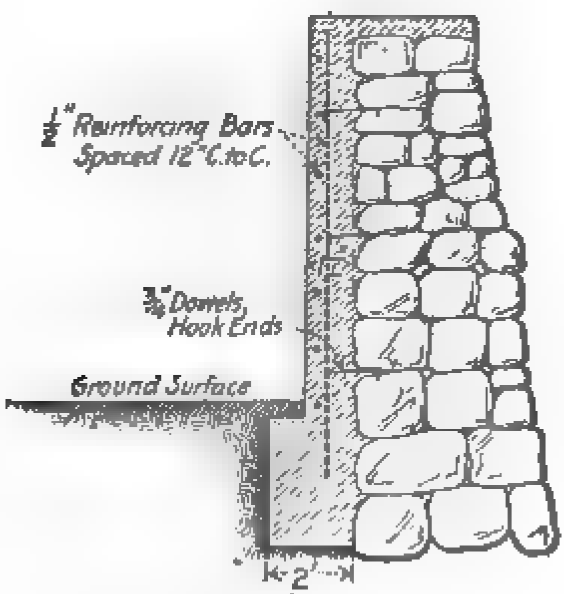
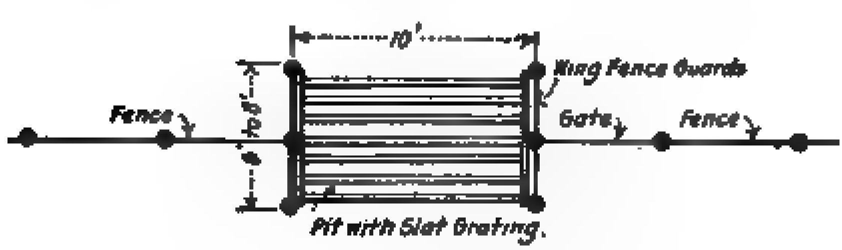


FIG. 58.—Facing for old masonry.



Cattle guard driveway.

Cattle Guards.—In western territory ranch owners will often grant road right-of-ways for a nominal sum but stipulate that the right-of-way shall not be fenced as it would cut off part of their range from water. The boundaries of these ranges are generally fenced and where the road passes this fence a gate must be used to prevent straying of cattle; it is more or less of a nuisance for every user of the road to open and close the gate and generally a gap is left in the fence across which a shallow pit 2′ to 3′ deep is dug and this is covered with a slat grating which cattle will not walk but which can be driven over by automobiles.

CHAPTER IX

MATERIALS

THE selection of materials is an important part of the design. Most municipal and State Departments have well equipped laboratories for testing stone, gravels, brick, bitumens, cements, etc. The object of these tests is to determine the physical and chemical properties that have a particular bearing on the action of the materials under construction conditions. While these conditions are not attained they are approximated and by a comparison of the laboratory results with the actual performance of the different materials in practice a relation can be established that is useful as a basis for judgment.

We are greatly indebted in this edition to Mr. H. S. Mattimore and Mr. J. E. Myers who have rearranged and brought up to date much of the material on tests and their significance.

This chapter gives a brief statement of the desirable qualities and the tests for:

1. Top course, macadam stone.
2. Screenings.
3. Bottom course, macadam stone.
4. Bottom course and sub-base fillers.
5. Brick.
6. Bituminous binders.
7. Concrete materials.

1. STONE FOR THE SURFACING OF MACADAM ROADS

Stone for use in the surfacing of a macadam road should be hard and tough to withstand the abrasive action of team traffic and the vibratory action of high-speed motor vehicles and should not contain any minerals that are likely to disintegrate rapidly under influence of weather conditions.

To determine the relative hardness, toughness and power to resist abrasive and impact action of traffic, stones are subjected to the following tests:

1. Abrasion.
2. Hardness.
3. Toughness.
4. Specific gravity.
5. Absorption.
6. Fracture.
7. Geological classification.

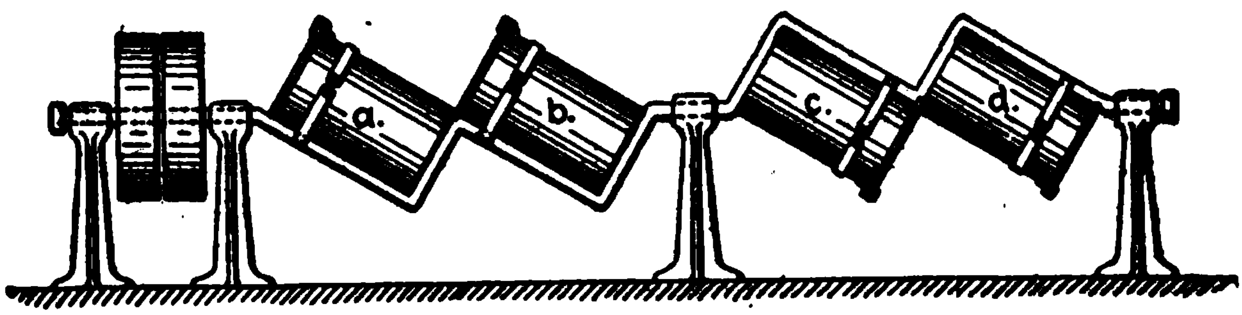
Abrasion Test.[1]—The machine shall consist of one or more hollow iron cylinders; closed at one end and furnished with a tightly fitting iron cover at the other; the cylinders to be 20 cm. in diameter and 34 cm. in depth, inside. These cylinders are to be mounted on a shaft at an angle of 30 deg. with the axis of rotation of the shaft.

At least 30 lb. of coarsely broken stone shall be available for a test. The rock to be tested shall be broken in pieces as nearly uniform in size as possible, and as nearly 50 pieces as possible shall constitute a test sample. The total weight of rock in a test shall be within 10 g. of 5 kg.

All test pieces shall be washed and thoroughly dried before weighing. Ten thousand revolutions, at the rate of between 30 and 33 per minute, shall constitute a test. Only the percentage of materials worn off which will pass through a 0.16 cm. (1/16 in.) mesh sieve shall be considered in determining the amount of wear. This may be expressed either as the percentage of the 5 kg. used in the test, or the French coefficient, which is in more general use, may be given; that is, coefficient of wear $= 20 \times \frac{20}{w} = \frac{400}{w}$, where w is the weight in grams of the detritus under 0.16 cm. (1/16 in.) in size per kilogram of rock used.

CONVERSION TABLE % OF WEAR TO FRENCH COEFFICIENT

F. Coef.	% of Wear	F. Coef.	% of Wear
20	2	8	5
13.3	3	6.7	6
10	4	5.7	7



Deval rattler.

Hardness.—Hardness is determined by a Dorry machine. A stone cylinder 25 cm. in diameter, obtained by a diamond core drill from the material to be tested, is weighed and placed in the machine so that one end rests on a horizontal cast-iron grinding disk with a pressure of 25 grams per sq. cm. The disk is revolved 1000 times during which standard crushed quartz sand about 1½ mm. in diameter is automatically fed to it. The cylinder is then removed and weighed and the coefficient of hardness obtained by the formula 20 − ⅓ the loss in weight, expressed in grams. In order to get

[1] American Society of Testing Materials.

reliable results two cylinders are generally used, each one being reversed end for end during the test.

Test for Toughness.[1]—1. Test pieces may be either cylinders or cubes, 25 mm. in diameter and 25 mm. in height, cut perpendicular to the cleavage of the rock. Cylinders are recommended as they are cheaper and more easily made.

2. The testing machine shall consist of an anvil of 50 kg. weight, placed on a concrete foundation. The hammer shall be of 2 kg. weight, and dropped upon an intervening plunger of 1 kg. weight, which rests on the test piece. The lower or bear-surface of this plunger shall be of spherical shape having a radius of 1 cm. This plunger shall be made of hardened steel, and pressed firmly upon the test piece by suitable springs. The test piece shall be adjusted, so that the center of its upper surface is tangent to the spherical end of the plunger.

3. The test shall consist of a 1 cm. fall of the hammer for the first blow, and an increased fall of 1 cm. for each succeeding blow until failure of the test piece occurs. The number of blows necessary to destroy the test piece is used to represent the toughness, or the centimeter-grams of energy applied may be used.

Determination of the Apparent Specific Gravity of Rock.[2]—The apparent specific gravity of rock shall be determined by the following method: First, a sample weighing between 29 and 31 g. and approximately cubical in shape shall be dried in a closed oven for 1 hour at a temperature of 110 degrees C. (230 degrees F.) and then cooled in a desiccator for 1 hour; second, the sample shall be rapidly weighed in air; third, trial weighings in air and in water of another sample of approximately the same size shall be made in order to determine the approximate loss in weight on immersion; fourth, after the balances shall have been set at the calculated weight, the first sample shall be weighed as quickly as practicable in distilled water having a temperature of 25 degrees C. (77 degrees F.); fifth, the apparent specific gravity of the sample shall be calculated by the following formula:

Apparent specific gravity $= \frac{W}{W - W_1}$ in which W = the weight in grams of the sample in air and W_1 = the weight in grams of the sample in water just after immersion.

Finally, the apparent specific gravity of the rock shall be the average of three determinations, made on three different samples according to the method above described.

Determination of the Absorption of Water per Cubic Foot of Rock.[3]—The absorption of water per cubic foot of rock shall be determined by the following method: First, a sample weighing between 29 and 31 g. and approximately cubical in shape shall be dried in a closed oven for 1 hour at a temperature of 110 degrees C. (230 degrees F.) and then cooled in a desiccator for 1 hour; second, the sample shall be rapidly weighed in air; third, trial weighings in air and in water

[1] American Society of Testing Materials.
[2] American Society of Testing Materials.
[3] American Society of Testing Materials.

of another sample of approximately the same size shall be made in order to determine the approximate loss in weight on immersion; fourth, after the balances shall have been set at the calculated weight, the first sample shall be weighed as quickly as possible in distilled water having a temperature of 25 degrees C. (77 degrees F.); fifth, allow the sample to remain 48 hours in distilled water maintained as nearly as practicable at 25 degrees C. (77 degrees F.) at the termination of which time bring the water to exactly this temperature and weigh the sample while immersed in it; sixth, the number of pounds of water absorbed per cubic foot of the sample shall be calculated by the following formula:

Pounds of water absorbed per cubic foot $= \frac{W_2 - W_1}{W - W_1} \times 62.24$ in which W = the weight in grams of sample in air, W_1 = the weight in grams of sample in water just after immersion, W_2 = the weight in grams of sample in water after 48 hours' immersion, and 62.24 = the weight in pounds of a cubic foot of distilled water having a temperature of 25 degrees C. (77 degrees F.).

Finally, the absorption of water per cubic foot of the rock, in pounds, shall be the average of three determinations made on three different samples according to the method above described.

Fracture.—Stone suitable for road work should crush in cubical shapes rather than in thin, flat pieces and preferably with rough, jagged fracture that it may interlock firmly under action of the roller.

Geological Classification.—The geological classification is determined from an examination with a microscope or powerful hand glass, and a consideration of its origin. Great refinements are avoided as the general classification is all that is necessary to the highway engineer after the physical qualities are ascertained by test.

Cost of Tests.—The cost of collecting and testing stone as given in the 1909 Report of the New York State Department of Highways is $8.55 per sample.

The following tables show tests on the more common rock:

TABLE. 23*a*. TAKEN FROM BULLETIN NO. 31, UNITED STAT[ES] OFFICE OF PUBLIC ROADS

Rock varieties	*Per cent wear	Toughness	Hardness	Cementing value	Specific gravity
Granite	3.5	15	18.1	20	2.65
Biotite-granite	4.4	10	16.8	17	2.64
Hornblende-granite	2.6	21	18.3	30	2.76
Augite-syenite	2.6	10	18.4	24	2.80
Diorite	2.9	21	18.1	41	2.90
Augite-diorite	2.8	19	17.7	55	2.98
Gabbro	2.8	16	17.9	29	3.00
Peridotite	4.0	12	15.2	28	3.40
Rhyolite	3.7	20	17.8	48	2.60
Andesite	4.7	11	13.7	189	2.50
Fresh basalt	3.3	23	17.1	111	2.90
Altered basalt	5.3	17	15.6	239	2.75
Fresh diabase	2.0	30	18.2	49	3.00
Altered diabase	2.5	24	17.5	156	2.95
Limestone	5.6	10	12.7	60	2.70
Dolomite	5.7	10	14.8	42	2.70
Sandstone	6.9	26	17.4	90	2.55
Feldspathic sandstone	3.3	17	15.3	119	2.70
Calcareous sandstone	7.4	15	8.3	60	2.66
Chert	10.8	15	19.4	27	2.50
Granite-gneiss	3.8	12	17.7	26	2.68
Hornblende-gneiss	3.7	10	17.1	30	3.02
Biotite-gneiss	3.2	19	17.5	41	2.76
Mica-schist	4.4	10	17.8	30	2.80
Biotite-schist	4.0	—	—	16	2.79
Chlorite-schist	4.2	—	—	24	2.90
Hornblende-schist	3.7	21	16.5	53	3.00
Amphibolite	2.9	10	19.0	29	3.00
Slate	4.7	12	11.5	102	2.80
Quartzite	2.9	19	18.4	17	2.70
Feldspathic quartzite	3.2	17	18.3	21	2.70
Pyroxene quartzite	2.3	27	18.6	17	3.00
Eclogite	2.4	31	17.4	21	3.30
Epodosite	3.6	16	16.0	47	3.03

*NOTE.—To convert % of wear to French coefficient, see Table on page 2[3].

TABLE 23b

FROM ANNUAL REPORT N. Y. STATE HIGHWAY COMM. 1914

County	Number of complete tests	Number of partial tests (no core piece)	Weight lbs. per cu. ft.	Water absorbed, lbs. per cu. ft.	French coefficient of abrasion	Hardness	Toughness	Weighted value
CALCAREOUS SANDSTONE								
Erie	5	...	167	0.65	9.5	12.9	13.4	68
Saratoga	6	...	169	0.31	10.1	15.9	13.8	76
Steuben	4	1	162	1.44	9.4	15.1	13.1	72
DOLOMITE								
Clinton	6	...	175	0.41	11.9	15.8	12.7	80
Dutchess	4	1	174	0.43	12.4	17.3	11.9	84
Essex	4	...	173	0.42	13.5	16.9	15.8	90
Franklin	4	...	174	0.51	9.5	14.9	12.1	70
Fulton	4	...	176	0.15	11.8	16.1	14.4	82
Herkimer	17	...	173	0.67	8.4	13.1	6.7	58
Monroe	13	2	171	1.07	10.3	14.8	8.2	69
Montgomery	8	...	174	0.39	10.6	14.7	11.5	73
Niagara	11	...	168	1.50	6.5	14.0	7.0	55
Saratoga	8	...	174	0.33	8.6	15.5	9.2	66
St. Lawrence	31	...	174	0.65	10.5	15.7	9.9	73
Washington	6	...	175	0.29	10.7	15.1	10.5	73
DOLOMITIC LIMESTONE								
Dutchess	8	1	176	0.46	9.0	14.9	10.9	68
Herkimer	4	1	170	0.47	11.3	16.7	8.2	76
Montgomery	8	1	175	0.41	13.0	15.8	12.4	83
Niagara	7	...	166	2.19	9.5	13.1	7.8	63
St. Lawrence	7	...	168	0.38	9.2	16.8	6.8	68
Washington	4	...	175	0.36	13.7	16.1	10.8	84
Wayne	4	...	173	0.59	10.2	15.5	8.7	71
GABBRO								
Essex	46	1	176	0.29	7.6	17.3	6.9	64
Warren	4	...	183	0.37	10.1	17.7	9.8	75
GNEISS								
Clinton	5	...	185	0.27	10.5	17.2	11.3	78
Dutchess	8	1	172	0.58	7.0	17.1	9.1	64
Essex	29	2	176	0.31	8.4	17.1	8.1	68
Franklin	8	...	178	0.50	6.2	16.1	7.8	59
Fulton	12	1	169	0.25	11.1	17.8	11.5	80
Hamilton	11	...	173	0.37	8.2	17.0	5.8	64
Jefferson	26	1	171	0.23	11.1	17.3	12.0	80
Lewis	6	...	167	0.27	9.6	17.9	10.6	75
Orange	7	...	179	0.38	7.1	17.1	6.4	62
Putnam	10	1	172	0.32	8.5	16.6	7.5	66
Saratoga	7	...	180	0.20	10.0	17.0	8.5	72
St. Lawrence	52	...	172	0.27	9.7	17.5	10.2	74
Warren	30	2	173	0.30	7.5	17.3	6.5	64
Washington	4	...	170	0.29	8.5	17.1	10.9	71
Westchester	37	2	171	0.39	8.3	16.9	7.8	67
GRANITE								
Essex	5	...	171	0.38	7.5	18.0	5.2	64
Franklin	6	...	165	0.31	8.7	17.9	9.4	71
Hamilton	5	...	165	0.36	9.9	18.1	9.0	75
Jefferson	23	1	166	0.23	12.1	18.4	10.1	83
Lewis	8	...	166	0.36	10.9	18.4	9.2	79
Oneida	6	...	166	0.13	10.2	18.9	8.2	77
St. Lawrence	30	...	165	0.25	9.9	18.3	8.1	74
Warren	5	...	165	0.45	7.9	17.9	7.7	67

FROM ANNUAL REPORT N. Y. STATE HIGHWAY COMM. 1914

County	Number of complete tests	Number of partial tests (no core piece)	Weight, lbs. per cu. ft.	Water absorbed, lbs. per cu. ft.	French coefficient of abrasion	Hardness	Toughness	Weighted value
Limestone								
Albany	13	7	168	0.60	7.9	14.3	6.4	59
Cayuga	34	6	170	0.49	8.8	14.9	7.8	64
Clinton	14	2	170	0.28	8.2	14.1	5.3	58
Columbia	12	...	170	0.28	9.1	15.3	9.2	67
Erie	9	3	167	0.57	8.1	16.6	8.3	66
Fulton	6	1	168	0.21	7.7	15.5	6.5	60
Genesee	6	3	169	0.26	8.0	15.0	8.2	62
Greene	11	...	169	0.36	11.1	16.4	8.9	75
Herkimer	17	9	169	0.26	8.7	14.8	8.2	64
Jefferson	105	44	169	0.28	7.6	15.1	6.4	59
Lewis	26	20	169	0.32	6.9	14.1	6.2	55
Madison	16	1	169	0.23	8.4	14.7	7.7	62
Monroe	4	...	168	0.27	8.1	14.1	7.4	60
Montgomery	12	2	169	0.24	8.5	15.3	8.0	64
Niagara	11	1	168	0.84	7.1	12.8	6.5	53
Oneida	31	19	169	0.29	7.8	13.8	6.6	58
Onondaga	25	1	170	0.38	8.9	15.7	8.4	67
Ontario	11	...	169	0.39	10.2	15.9	10.2	73
Otsego	7	2	169	0.32	8.1	14.1	6.3	59
Rensselaer	4	1	171	0.21	7.5	15.0	5.3	58
Saratoga	5	...	170	0.24	8.7	13.7	7.0	60
Schoharie	29	2	169	0.34	8.1	14.9	6.7	61
Seneca	7	3	169	0.21	9.4	15.3	7.9	67
Ulster	12	3	170	0.25	8.1	15.6	7.4	63
Warren	5	...	170	0.24	8.9	15.7	7.4	66
Washington	5	3	169	0.34	7.9	15.5	6.9	62
Marble								
Dutchess	4	...	178	0.30	7.3	14.2	6.0	56
Quartzite								
Columbia	16	...	168	0.28	16.5	18.3	17.1	103
Dutchess	8	2	166	0.36	13.5	18.8	11.8	90
Rensselaer	10	...	166	0.49	12.1	18.7	14.8	89
Washington	12	...	167	0.40	14.6	18.9	16.3	98
Sandstone								
Allegany	8	...	156	2.10	8.4	13.4	9.1	61
Broome	11	...	165	1.29	7.8	12.9	10.5	60
Cayuga	4	1	167	1.16	7.8	12.1	10.5	58
Chenango	15	1	164	1.58	8.7	11.2	10.4	59
Clinton	14	...	163	0.71	11.7	18.5	11.0	83
Delaware	53	2	167	1.45	7.0	12.7	8.5	55
Erie	8	1	159	2.10	6.3	5.1	7.8	37
Franklin	5	...	157	1.06	9.7	17.9	7.1	72
Greene	6	...	169	0.62	8.6	14.5	8.1	63
Herkimer	4	...	160	2.50	10.9	16.4	10.7	76
Jefferson	8	...	156	1.46	8.3	16.2	6.3	64
Livingston	4	...	160	3.02	8.8	9.6	8.8	54
Madison	5	...	163	2.15	9.9	13.9	8.6	66
Niagara	7	...	158	1.78	9.0	16.4	8.2	68
Orleans	8	...	155	2.18	11.8	14.4	8.1	72
Otsego	21	1	162	1.75	8.4	11.9	9.6	59
Saratoga	5	...	163	0.36	10.7	18.0	8.7	77

FROM ANNUAL REPORT N. Y. STATE HIGHWAY COMM. 1914.—*Cont.*

County	Number of complete tests	Number of partial tests (no core piece)	Weight, lbs. per cu. ft.	Water absorbed, lbs. per cu. ft.	French coefficient of abrasion	Hardness	Toughness	Weighted value
				SANDSTONE.—*Continued*				
Schoharie	6	3	165	1.21	9.4	15.2	11.7	70
Schuyler	4	...	162	2.14	8.1	11.6	10.6	58
Seneca	5	...	165	0.86	11.0	13.9	15.8	77
Steuben	22	3	157	2.79	8.3	9.3	10.0	54
St. Lawrence	16	...	159	0.79	10.0	17.8	7.2	73
Sullivan	30	4	164	1.26	6.5	14.9	8.2	58
Ulster	8	...	166	0.64	8.0	14.3	8.1	61
Wyoming	7	...	159	2.54	6.0	5.1	7.9	36
				SANDY GRIT				
Albany	5	...	167	0.75	7.5	13.2	7.2	56
Columbia	12	...	168	0.32	10.7	15.9	11.7	76
Dutchess	10	2	168	0.57	8.1	16.2	11.5	68
Greene	13	...	169	0.48	7.1	15.6	9.5	62
Montgomery	4	...	166	1.39	10.1	11.3	11.8	65
Rensselaer	10	...	169	0.44	9.1	15.9	9.4	69
Saratoga	5	...	168	0.99	11.8	15.2	11.9	78
Schenectady	4	...	165	1.10	9.2	14.6	9.5	66
Ulster	7	...	169	0.59	7.5	13.8	10.2	60
				SYENITE				
Essex	7	...	184	0.52	7.7	17.1	6.7	64
Franklin	4	...	171	0.45	10.1	18.3	8.0	75
Herkimer	13	...	174	0.16	12.5	18.0	11.6	85
Jefferson	7	...	176	0.34	12.4	18.1	14.5	88
				TRAP				
Rockland	12	...	183	0.39	13.2	17.6	1.64	91

TABLE 23*bb*. GEOLOGICAL CLASSIFICATION

Class	Type	Family
I Igneous	1 Intrusive (plutonic)	*a* Granite *b* Syenite *c* Diorite *d* Gabbro *e* Peridotite
	2 Extrusive (volcanic)	*a* Rhyolite *b* Trachyte *c* Andesite *d* Basalt and diabase
II Sedimentary	1 Calcareous	*a* Limestone *b* Dolomite
	2 Siliceous	*a* Shale *b* Sandstone *c* Chert (flint)
III Metamorphic	1 Foliated	*a* Gneiss *b* Schist *c* Amphibolite
	2 Nonfoliated	*a* Slate *b* Quartzite *c* Eclogite *d* Marble

[1] Bulletin No. 31, United States Department of Public Roads.

The following quotation from bulletin No. 31 O. P. R. & R. E. describes the characteristics of the three groups:

Igneous Rocks.—"All rocks of the igneous class are presumed to have solidified from a molten state, either upon reaching the earth's surface or at varying depths beneath it. The physical conditions, such as heat and pressure, under which the molten rock magma consolidated, as well as its chemical composition and the presence of included vapors, are the chief features influencing the structure. Thus, we find the deep-seated, plutônic rocks coarsely crystalline with mineral constituents well defined, as in case of granite rocks, indicating a single, prolonged period of development, whereas the members of the extrusive or volcanic types, solidifying more rapidly at the surface, are either fine-grained or frequently glassy and vesicular, or show a porphyritic structure. This structure is produced by the development of large crystals in a more or less dense and fine-grained ground mass, and is caused generally by a recurrence of mineral growth during the effusive period of magmatic consolidation.

"In the arrangement of the rock families from a mineralogical standpoint it will be noted that the plutonic rock types, granite, syenite, and diorite, are represented by their equivalent extrusive varieties, rhyolite and andesite, and that diabase has been included, somewhat arbitrarily, with basalt, as a volcanic representative of gabbro. These latter rocks are of special interest, owing to their wide distribution and general use in road construction. They occur in the forms of dykes, intruded sheets, or volcanic flows, and vary in structure from glassy-porphyritic (typical basalt) to wholly crystalline and even granular (diabase). Their desirable qualities for road-building are caused to a large extent by a peculiar interlocking of the mineral components (ophitic structure), yielding a very tough and resistant material well qualified to sustain the wear of traffic.

"Igneous rocks vary in color from the light gray, pink, and brown of the acid granites, syenites, and their volcanic equivalents (rhyolite, andesite, etc.) to the dark steel-gray or black of the basic gabbro, peridotite, diabase, and basalt. The darker varieties are commonly called trap. This term is in very general use and is derived from *trappa*, Swedish for stair, because rocks of this kind on cooling frequently break into large tabular masses, as may be seen in the exposures of diabase on the west shore of the Hudson River from Jersey City to Haverstraw.

Sedimentary Rocks.—"The sedimentary rocks as a class represent the consolidated products of former rock disintegration, as in the case of sandstone, conglomerate, shale, etc., or they have been formed from an accumulation of organic remains chiefly of a calcareous nature, as is true of limestone and dolomite. These fragmental or clastic materials have been transported by water and deposited mechanically in layers on the sea or lake bottoms, producing a very characteristic bedded or stratified structure in many of the resulting rocks.

"In the case of certain oolitic and travertine limestones, hydrated iron oxides, siliceous deposits, such as geyserite, opal, flint, chert,

etc., the materials have been formed chiefly by chemical precipitation and show generally a concentric or colloidal structure.[1] Oolitic and pisolitic limestones consist of rounded pealike grains of calcic carbonate held together by a calcareous cement. Travertine is the so-called 'onyx marble' of Mexico and Arizona. It is a compact rock, concentric in structure and formed by the precipitation of carbonate of lime from the waters of springs and streams.

"Loose or unconsolidated rock débris of a prevailing siliceous nature comprise the sands, gravels, finer silts, and clays (laterite, adobe, loess, etc.). Shell sands and marls, on the other hand, are mainly calcareous, and are formed by an accumulation of the marine shells and of lime-secreting animals. Closely associated with the latter deposits in point of origin are the beds of diatomaceous or infusorial earth composed almost entirely of the siliceous casts of diatoms, a low order of seaweed or algæ.

"This unconsolidated material may pass by imperceptible gradations into representative rock types through simple processes of induration. Thus clay becomes shale, and that in turn slate, without necessarily changing the chemical or mineralogical composition of the original substance.

"Such terms as flagstone, freestone, brownstone, bluestone, graystone, etc., are generally given to sandstones of various colors and composition, while puddingstone, conglomerate, breccia, etc., apply to consolidated gravels and coarse feldspathic sands.

"The calcareous rocks are of many colors, according to the amount and character of the impurities present.

Metamorphic Rocks.—"Rocks of this class are such as have been produced by prolonged action of physical and chemical forces (heat, pressure, moisture, etc.) on both sedimentary and igneous rocks alike. The foliated types (gneiss, schist, etc.) represent an advanced stage of metamorphism on a large scale (regional metamorphism), and the peculiar schistose or foliated structure is due to the more or less parallel arrangement of their mineral components. The non-foliated types (quartzite, marble, slate, etc.) have resulted from the alteration of sedimentary rocks without materially affecting the structure and chemical composition of the original material.

"Rocks formed by contact metamorphism and hydration, such as hornfels, pyroxene marble, serpentine, serpentineous limestone, etc., are of great interest from a petrographical standpoint, but are rarely of importance as road materials.

"The color of metamorphic rocks varies between gray and white of the purer marbles and quartzites to dark gray and green of the gneisses, schists, and amphibolites. The green varieties are commonly known as greenstones, or greenstone schists."

Interpretation of Tests.—It has been found impractical to specify definite qualities of stone for use in macadam highways. Economy and practical engineering demand that all available sources be considered. Tests are made to determine the relative qualities of stone from these different sources and the results used as a guide for selection.

[1] G. P. Merrill's "Rocks, Rock Weathering, and Soils," 1897, pp. 104–114.

In the work of the New York State Highway Commission all tests are tabulated geographically, using a county as a unit. Table No. 23*b* is compiled from the records of this department. It will be noted that comparisons are made in different classifications only, as it is considered that conclusions should not be drawn from a comparison of tests procured from materials having different origins and composed of different minerals.

For the purpose of ready comparison, there has been introduced a figure known as the "weighted value." (See last column Table 23*b*.) This is computed by giving relative weights of three to the French coefficient, two to the hardness, one to the toughness values and adding the three together. These relative weights were determined from a consideration of the amount of material used in the different tests and the personal equation in running them.

By consulting these tables the available rocks of different classifications in various sections throughout New York State can be determined readily, and as new tests are completed they are compared with good average material from that section.

Conclusions.—Trap (diabase), granite, gneiss, quartzite, sandstone and limestone are the most common rocks and when found in a good state of preservation make good surfacing materials.

As generally found, trap is uniform in hardness and toughness, making an excellent material for use in top course.

Granite and gneiss, where they occur with hornblende replacing a large percentage of the quartz, make an excellent surfacing stone.

Quartzites when found in good state of preservation are hard and tough. They should not be confused with crystalline quartz which is hard but brittle.

Sandstones are extremely variable and only the better varieties should be used.

Limestones range from the fine grained dense products which are hard and tough to the coarse grained soft products which are not suitable for surfacing.

Screenings.—Screenings act as a filler and binder for waterbound macadam and as a partial filler for bituminous macadam. For use in waterbound construction the main mineral constituent is the most essential feature to be considered as this must be a material that will from a binder and "puddle" readily when subjected to the action of a road roller and water.

Limestone screenings have proved the most efficient as a binder in waterbound construction, although trap and some other igneous rocks can be bound with their own dust by repeated puddling. Screenings consisting mainly of quartz have never been used successfully in waterbound construction except by the addition of some limestone screenings. The use of a percentage of clay or loam as a binder is not advisable except where the cost of limestone screenings would be prohibitive.

Laboratory methods for testing the cementing power of rock powders are available but the results obtained are erratic and undependable.

In plain waterbound roads it is often necessary to mix some lime-

stone screenings, fine sandy loam, or even a small percentage of clay loam with trap, granite, sandstone, quartzite, or gneiss screenings to get a good bond and prevent raveling in dry weather.

3. BOTTOM COURSE MACADAM STONE

As the bottom stone simply spreads the wheel loads transmitted through the top course and is not directly subjected to the traffic action, almost any stone that breaks into cubical irregular shapes that will not air or water slake and that is hard enough to stand the action of the roller during construction will be satisfactory.

Any of the materials listed above in Table 24 except shale and slate can be used, provided that they are not rotten from long exposure in the air. The different available varieties are usually tested in the same manner as for top stone in order to pick the best. Acid blast furnace crushed slag makes an excellent bottom course but s not uniform enough for top course.

4. FILLERS

Fillers are used in the bottom course to fill the voids between the crushed stone and to prevent rocking or sidewise movement of the larger pieces.

They should be easy to manipulate in placing, should not soften when wet, or draw water up from the subgrade by capillary action.

The materials most used are

Coarse sandy loam
Coarse sand
Gravel with large excess of fine material
Stone screenings

The fitness of the material can be determined by inspection and by wetting a handful; if it gets sticky or works into a soft mud it should not be used.

5. VITRIFIED BRICK

Bricks must withstand the same destructive agencies as described for top stone. They must be uniform in size, tough, hard, dense, evenly burned, and, on account of their peculiar shape, must have a high resistance against rupture. These properties are tested by the standard methods adopted by the American Brick Manufacturers' Association, as described in the New York State specifications on page 730.

It should be understood that bricks suitable for paving are manufactured in a different way and of different materials than ordinary building bricks.

"The materials for molding any paving brick must be of a peculiar character which will not melt and flow when exposed to an intense heat for a number of days but will gradually fuse and form vitreous combinations throughout while still retaining its form.

"The resulting brick must be a uniform block of dense texture in

which the original stratification and granulation of the clay has been wholly lost by fusion which has stopped just short of melting the clay and forming glass.

"The clay while fusing must shrink equally throughout, thus causing the brick to be without laminations or of any exterior vitrified crust differing from the interior."[1]

The great majority of paving brick are made in Ohio, Illinois, Indiana, Pennsylvania, West Virginia, and New York. They are classed as shale or fire-clay brick.

6. BITUMINOUS BINDERS

The subject of bitumens is an intricate one and the reader is referred to the works of Clifford Richardson, Prevost Hubbard, and others, for detailed information, as a book of this character can give only an outline.

There are a number of dust preventives and road binders on the market which depend for their effectiveness on a bituminous binding base. The term bitumen is applied to a great many substances. Hubbard arbitrarily defines bitumens as "consisting of a mixture of native or pyrogenetic hydrocarbons and their derivatives, which may be gaseous, liquid, a viscous liquid, or solid, but if solid melting more or less readily upon the application of heat, and soluble in chloroform, carbon bisulphide, and similar solvents."[2]

The bitumens may be classified as native and artificial. The native bituminous materials, that are used in road work, are the asphaltic and semi-asphaltic oils (dust layers), Malthas (the binding base of Rock Asphalts), Trinidad, Bermudez California, and Cuba asphalts, Gilsonite, and Grahamite (which, however, are too brittle in their natural state and require fluxing with a suitable residual oil before they can be used as binders). The natural asphalts are refined to remove water and any objectionable amount of impurities by heating until the gases are driven off, skimming the vegetable matter which rises to the surface, and removing the mineral constituents which fall to the bottom.

The artificial bituminous materials are derived by the destructive distillation of coal, or by fractional distillation of crude coal tars, or the native petroleum oils. They comprise the crude coal and water gas tars, the refined tars, the residual oils and semi-solid binders derived from the petroleum oils. They vary greatly in consistency and binding power.

The following material is briefed from Bulletin No. 34, United States Office of Public Roads: The light oils and tars have a relative small percentage of bituminous base and are effective only so long as it retains its binding power; the more permanent binders contain a larger percentage of bitumen; these are the heavy oils and semi-solids.

Artificial Bitumens

Crude Tars.—Coke ovens and gas plants produce most of the coal tars in use. These tars contain various complex combinations

[1] Judson's "Roads and Pavements," page 87.
[2] "Dust Preventives and Road Binders." John Wiley & Sons.

of carbon, hydrogen, and oxygen and small amounts of nitrogen and sulphur. They vary in composition according to the material from which they are made and the temperature at which they are distilled. The percentage of free carbon ranges from 5 per cent. to 35 per cent., and the bitumen from 60 per cent. to 95 per cent., depending on the temperature of manufacture. Tars produced at high temperatures contain free carbon in excess which weakens their binding power; they, also, contain a large amount of anthracine and naphthalene, two useless materials from the standpoint of road work. Tars produced at low temperatures are to be preferred. Coke tar is low temperature tar; gas tar is high temperature tar.

Refined Tars.—Much of the road tar is refined tar—that is, it has been subjected to fractional distillation to remove the valuable volatile compounds. The residuum from this process is a thick viscous material known as coal-tar pitch, and if the crude tar from which it is obtained was produced at a low temperature it is nearly pure bitumen; the dead oils obtained from the distillation are of little value and are often run back into the pitch, which makes it liquid when cold. The following table gives the approximate composition of water-gas tar, crude coal tar, and refined tar.

TABLE 23*c*. SPECIFIC GRAVITY AND COMPOSITION OF TAR PRODUCTS

Table from Bulletin No. 34 United States Office of Public Roads

Kind of Tar	Specific Gravity	Ammoniacal Water	Total Light Oils to 170° C.	Total Dead Oils 170° 270° C.	Residue (by Difference)
		%	%	%	%
Water-gas tar . . .	1.041	2.4	*a*21.6	*b*52.0	*c*24.0
Crude coal tar . .	1.210	2.0	*d*17.2	*e*26.0	*f*54.8
Refined coal tar .	1.177	0.0	*b*12.8	*g*47.6	*f*39.6

a Distillate mostly liquid.
b Distillate all liquid.
c Pitch very brittle.
d Distillate mostly solid.
e Distillate one-half solid.
f Pitch hard and brittle.
g Distillate one-third solid.

Table 23*d* gives a more up-to-date analysis of the coal tars on the market.

The tests and detailed requirements for light, medium, and heavy bitumens are given in specifications, page 721.

If the tar is used as a temporary dust-layer only, it should be a low-temperature, dehydrated tar, liquid when cold. If used as a more permanent binder and applied hot, it should have a larger percentage of pitch, should contain no water, and be free from an excessive amount of free carbon. If used as a mastic in butuminous macadam, it should contain a high percentage of pitch and be free from the defects mentioned.

Natural Bitumens and Artificial Residual Oils and Semi-solids.— Mineral oils can be classed as paraffin petroleums, mixed paraffin and asphaltic petroleums, and asphaltic petroleums. The relative value of oils as a source of supply for road materials depends on their percentage of asphaltic residue. The eastern oils found in New York, Pennsylvania, West Virginia, etc., are paraffin petroleums; the western oils vary from light to heavy asphaltic petroleums, and the southern oils have a mixed paraffin and asphaltic base.

The crude petroleum is refined by fractional distillation to obtain its valuable products, such as kerosene, etc. The character of the residue depends, as for the tars, on the crude material and the method of manufacture; the operation known as "cracking," which is used to increase the yield of the inflammable oils, produces an excess of free carbon.

The paraffin petroleum residuums are soft and greasy and are not suitable for road work; they contain a large amount of the paraffin hydrocarbons and paraffin scale (crude paraffin).

The California petroleum residuums resemble asphalt, and if carefully distilled without cracking should contain little or no free carbon. They are suited to road work.

The Texas, or semi-asphaltic petroleums contain some paraffin hydrocarbons and about 1 per cent. of paraffin scale. Residuums from these oils, if containing a relatively small amount of paraffin, can be successfully used.

The tests and required properties of residuum bituminous binders used on the New York State roads in 1914 are given in specifications, page 721.

The following tables give a general idea of the relative characteristics of the crude petroleums and petroleum residuums.

Results of Tests of Crude Petroleum

Tables from Bulletin No. 34 United States Office of Public Roads

Kinds of Oil	Specific Gravity	Flash Point ° C.	Volatility at 110° C. 7 Hours	Volatility at 160° C. 7 Hours	Volatility at 205° C. 7 Hours	Residue
			%	%	%	%
Pennsylvania, paraffin....	0.801	(*a*)	47.3	58.0	68.0	*b*32.0
Texas, semi-asphaltic	.904	43	20.0	27.0	49.0	*c*51.0
California, asphaltic	.939	26	....	....	*d*42.7	*e*57.3

a Ordinary temperature
b Soft
c Quick flow
d Volatility at 200°, 7 hours.
e Soft maltha; sticky

(*Continued on page* 248)

TABLE 23*d*. CIRCULAR NO. 97, U. S. OFFICE OF PUBLIC ROADS

Analysis of crude coke-oven tars produced in the United States and Canada.

Serial No.	General Information		
	Company and location	Type of Oven	Maximum temperature of firing retorts
5126	Solvay Process Co., Syracuse, N.Y.	Semet-Solvay	1650–1450° C.
5123	Semet-Solvay Co., Pennsylvania Steel Co., Steelton, Pa.	“	1050–1450° C.
5124	Semet-Solvay Co. National Tube Co., Benwood, W.Va.	“	1050–1450° C.
5137	Semet-Solvay Co., Milwaukee Coke & Gas Co., Milwaukee, Wis.	“	1050–1450° C.
5121	Semet-Solvay Co. Pennsylvania Steel Co., Lebanon, Pa.	“	1050–1450° C.
5125	By-Products Coke Corporation, South Chicago, Ill	“	1050–1450° C.
5128	Semet-Solvay Co., Detroit, Mich.	“	1050–1450° C.
5200	Semet-Solvay Co., Empire Coke Co., Geneva, N.Y.	“	1050–1450° C.
5189	Semet-Solvay Co., Dunbar Furnace Co., Dunbar, Pa.	“	1050–1450° C.
5160	Semet-Solvay Co., Central Iron & Coal Co., Tuscaloosa, Ala.	“	1250° C.
5074	Philadelphia Suburban Gas & Electric Co., Chester, Pa.	“	1050° C.
5081	Semet-Solvay Co., Ensley, Ala.	“	1250° C.
5095	The N. E. Gas & Coke Co., Everett, Mass.	Otto Hoffman	[1] 1100° C.
5083	Lackawanna Steel Co., Lackawanna Iron & Steel Co., Lebanon, Pa.	“	1000° C. (1800° F.)
5159	Dominion Tar & Chemical Co., Sydney, Nova Scotia	“	[2]
5107	Hamilton Otto Coke Co., Hamilton, Ohio.	“	1111° C. (2000° F.)
5086	Carnegie Steel Co., South Sharon, Pa.	United Otto	1666° C. (3000° F.)
5078	Maryland Steel Co., Sparrows Point, Md.	“	1333° C. (2400 F.)
5087	Citizens' Gas Co., Indianapolis, Ind.	“	1222° C. (2200 F.)
5109	Pittsburg Gas & Coke Co., The United Coke & Gas Co., Glassport, Pa.	“	[2]
5122	Zenith Furnace Co., Duluth, Minn.	“	1222-1277° C. 2200-2300° F.
5188	Illinois Steel Co., Joliet, Ill.	Koppers	1444° C. (2600° F.)
5404	Illinois Steel Co., Indiana Steel Co., Gary, Ind.	“	1100° C.
5108	Camden Coke Co., Camden, N.J.	Otto Hoffman United Otto	1000° C. (1800° F.) 1222° C. (2200° F.)
5127	Cambria Steel Co., Johnstown, Pa.	Otto Hoffman United Otto	1111° C. (2000° F.) 1111° C. (2000° F.)
5089	Lackawanna Steel Co., Buffalo, N.Y.	United Otto Rothberg	1000° C. (1800° F.) 1000° C. (1800° F.)

TABLE 23d. *Continued*

Answers to Questions			Examination			
Maximum temperature to which coal is brought	Specific gravity of crude tar	Per cent of free carbon in tar	Specific gravity of tar, 25° C.	Per cent of free carbon	Per cent of ash	Per cent soluble in CS_2 including H_2O
950–1150° C.	1.12–1.21	3–12	1.195	7.76	0.12	92.12
950–1150° C.	1.12–1.21	3–12	1.206	8.77	.07	91.16
950–1150° C.	1.12–1.21	3–12	1.176	7.14	.04	92.82
950–1150° C.	1.12–1.21	3–12	1.168	6.10	.05	93.85
950–1150° C.	1.12–1.21	3–12	1.173	4.71	.06	95.23
950–1150° C.	1.12–1.21	3–12	1.191	7.49	.03	92.48
950–1150° C.	1.12–1.21	3–12	1.169	6.56	.11	93.33
950–1150° C.	1.12–1.21	3–12	1.159	6.07	.08	93.85
950–1150° C.	1.12–1.21	3–12	1.181	8.85	.02	91.13
1150° C.	1.17	5.72	1.159	5.05	.02	94.93
1000° C.	1.16 (20° C.)	—	1.141	3.96	.05	95.99
1150° C.	1.17 (15° C.)	8	1.175	6.90	.06	93.04
[1] 1200° C.	1.17	8–10	1.160	13.94	.00	86.06
1000° C. (1800° F.)	1.10	16–24	1.214	14.05	.13	85.82
(2)	1.170	10–15	1.143	10.81	.05	89.14
1111° C. (2000° F.)	1.14	[6] 16.0	1.160	8.37	.06	91.57
1444° C. (2600° F.)	1.2	7.09–10.64	1.191	7.89	.03	92.08
1222° C. (2200° F.)	[3] 1.19	[3] 8–10	1.179	8.49	.03	91.48
1222° C. (2200° F.)	1.14–1.15	4–5	1.133	5.21	.07	94.72
(2)	(50° F.) 1.207 10° C.	16.59	1.176	10.53	.04	89.43
(2)	(2)	(2)	1.195	12.18	.05	87.77
1388° C (2500° F.)	1.16–1.20	12–15	1.171	3.89	.06	96.05
880–950° C.	[4] 1.174 1.169	4.35	1.169	2.73	.04	97.23
833° C. (1500° F.) 1055° C. (1900°F.)	1.20–1.30 [5] (1.221)	7–9 [5] (7.3)	1.182	11.30	.06	88.64
[1] 1111° C. (2000° F.) [1] 1111° C. (2000° F.)	1.12	[1] 15	1.211	12.40	.16	87.44
1000° C. (1800° F.) 1000° C. (1800° F.)	1.16	16–24	1.210	16.80	.00	83.2[c]

TABLE 23*d*. *Continued*

Serial No.	Company and Location	Examination, Public Roads			
		Distillation results			
		Water		Light oils up to 110° C.	
		% by vol.	% by weight	% by vol.	% by weight
5126	Solvay Process Co., Syracuse, N.Y.	1.0	0.8	[8] 0.3	0.3
5123	Semet-Solvay Co., Pennsylvania Steel Co.; Steelton, Pa.	1.0	.8	.4	.3
5124	Semet-Solvay Co., National Tube Co., Benwood, W.Va.	1.1	1.0	1.9	1.5
5137	Semet-Solvay Co., Milwaukee Coke & Gas Co., Milwaukee, Wis.	1.8	1.5	1.4	1.2
5121	Semet-Solvay Co., Pennsylvania Steel Co., Lebanon, Pa.	.6	.5	1.6	1.3
5125	By-Products Coke Corporation, South Chicago, Ill.	[7]	[7]	.4	.3
5128	Semet-Solvay Co., Detroit, Mich.	6.9	5.9	[9] 2.8	2.3
5200	Semet-Solvay Co., Empire Coke Co., Geneva, N.Y.	4.0	3.4	2.6	2.1
5189	Semet-Solvay Co., Dunbar Furnace Co., Dunbar, Pa.	2.0	1.7	1.7	1.4
5160	Semet-Solvay Co., Central Iron & Coal Co., Tuscaloosa, Ala.	3.2	2.8	2.4	1.9
5074	Philadelphia Suburban Gas & Electric Co., Chester, Pa.	2.3	2.0	2.3	1.3
5081	Semet-Solvay Co., Ensley, Ala.	3.3	2.8	[8] 1.4	1.0
5095	The New England Gas & Coke Co., Everett, Mass.	2.2	2.0	2.9	2.3
5083	Lackawanna Steel Co., Lackawanna Iron & Steel Co., Lebanon, Pa.	5.4	4.4	[9] 1.4	1.4
5159	Dominion Tar & Chemical Co., Sydney, Nova Scotia	3.2	2.8	[1.9	1.5
5107	Hamilton Otto Coke Co., Hamilton, O.	3.4	3.0	3.1	2.5
5086	Carnegie Steel Co., South Sharon, Pa.	1.0	1.0	[9] 1.6	1.2
5078	Maryland Steel Co., Sparrows Point, Md.				
5087	Citizens' Gas Co., Indianapolis, Ind.	1.6	1.3	1.3	.9
5109	Pittsburg Gas & Coke Co., The United Coke & Gas Co., Glassport, Pa.	1.2	1.1	1.1	.9
5122	Zenith Furnace Co., Duluth, Minn.	1.1	1.0	1.1	.9
5188	Illinois Steel Co., Joliet, Ill.	3.6	3.0	1.7	1.3
5404	Illinois Steel Co., Indiana Steel Co.,	1.9	1.6	[9] 1.7	1.2
	Gary, Ind.	3.5	3.0	[9] 1.3	1.0
5108	Camden Coke Co., Camden, N.J.	2.2	1.9	1.8	1.4
5127	Cambria Steel Co., Johnstown, Pa.	10.1	8.3	[9] 3.1	2.3
5089	Lackawanna Steel Co., Buffalo, N.Y.	2.7	2.2	[10] .5	.3

REFERENCES TO TABLE 23 *d*

[1] Approximately.
[2] No information.
[3] Varies with coal. Coal with 28 per cent of volatile matter used.
[4] With H_2O.
[5] At present.
[6] Variable.
[7] Trace.
[8] Trace of solids.
[9] Distillate, solid.
[10] Distillate, one-fourth solid.
[11] Distillate, nine-tenths solid.
[12] Distillate, three-fourths solid.
Distillate, eight-ninths solid.
[14] Distillate, one-half solid.

TABLE 23*d*. *Continued*

Examination, Office of Public Roads								
Distillation results								
Middle oils, 110°–170 C.		Heavy oils, 170°–270 C.		Heavy oils, 270°–315° C.		Pitch		Serial No.
% by vol.	% by weight	% by vol.	% by weight	% by vol.	% by weight	% by vol.	% by weight	
0.8	0.7	[12] 13.1	11.5	[19] 8.2	7.3	[25] 76.6	79.1	5126
[9] 2.0	1.7	[9] 14.0	12.3	[20] 7.9	6.9	[26] 74.7	77.6	5123
.7	.6	14.9	13.2	[21] 11.9	10.6	[27] 69.5	73.1	5124
.8	.6	[13] 21.1	18.9	[20] 5.5	4.9	[26] 69.4	72.5	5137
.8	.6	[14] 17.5	15.5	[19] 9.4	8.4	[26] 70.1	73.7	5121
[12] 1.1	.9	[15] 23.6	20.7	[9] 9.8	8.9	[27] 65.1	68.9	5125
[9] .4	.3	[11] 14.6	13.0	[8] 6.9	5.7	[28] 68.4	72.0	5128
.6	.5	[10] 17.6	15.5	[22] 11.4	10.4	[27] 63.8	67.7	5200
.2	.2	[16] 20.0	17.8	[21] 6.5	5.7	[26] 69.6	73.1	5189
.3	.3	18.6	16.3	[10] 7.5	6.8	[27] 68.0	71.5	5160
1.2	.8	22.8	19.5	[19] 13.6	12.5	57.8	62.0	5074
.2	.2	[17] 16.5	14.1	[14] 9.3	8.2	[27] 69.3	73.2	5081
.6	.5	23.5	20.4	[17] 15.6	14.4	[27] 55.2	59.7	5095
[9] .1	.1	[11] 13.0	10.9	[21] 9.4	8.1	[25] 70.7	74.6	5083
.6	.5	27.2	24.2	[19] 7.3	6.7	[27] 59.8	63.5	5159
.7	.6	27.9	24.4	[19] 3.8	3.5	[27] 61.1	64.9	5107
[9] .6	.4	[16] 12.1	10.2	[19] 11.0	9.7	[26] 73.7	77.5	5086
.6	.4	[12] 17.2	15.1	[21] 9.6	8.5	[28] 69.7	73.2	5078
1.4	1.3	23.9	21.4	[10] 11.6	10.4	[27] 60.8	64.7	5087
.5	.4	[18] 26.9	23.6	[14] 6.9	6.3	[27] 63.5	67.6	5109
.4	.3	[11] 18.1	15.9	[19] 12.5	11.1	[27] 63.7	67.8	5122
[9] .2	.2	[9] 20.0	18.0	[11] 13.4	12.0	[26] 62.8	66.3	5188
[9] .4	.3	[9] 20.6	18.5	[9] 7.1	6.5	[28] 67.1	70.2	5404
.6	.5	[14] 20.5	18.2	[23] 8.5	7.5	[26] 66.4	70.1	5108
[9] .3	.2	[9] 7.1	6.1	[12] 7.4	6.9	[28] 72.0	74.8	5127
[9] 2.2	1.7	[9] 11.7	9.9	[24] 11.8	10.2	[27] 71.1	75.0	5089

REFERENCES TO TABLE 23 *d*

[15] Distillate, two-thirds solid.
[16] Distillate, four-fifths solid.
[17] Distillate, seven-eighths solid.
[18] Distillate, one-ninth solid.
[19] Distillate, one-third solid.
[20] Distillate, one-sixth solid.
[21] Distillate, one-fifth solid.
[22] Distillate, two-fifths solid.
[23] Distillate, one-seventh solid.
[24] Distillate, three-fifths solid.
[25] Pitch, soft and sticky.
[26] Pitch, very soft and sticky.
[27] Pitch, hard and brittle.
[28] Pitch, plastic.

RESULTS OF PETROLEUM RESIDUUM

Kinds of Oil	Specific Gravity	Flash Point ° C.	Volatility at 200° C. 7 Hours	Residue	Solid Paraffin	Fixed Carbon
			%	%	%	%
Pennsylvania, paraffin....	0.920	186	14.2	a85.8	11.0	3.0
Texas, semi-asphaltic	.974	214	6.2	a93.8	1.7	3.5
California, asphaltic	1.006	191	17.3	a82.7	0.0	6.0

a Soft.

Tests of Bitumens and Their Significance.—Bitumens for use as the cementing material in road construction may, according to their source and characteristics, be divided into the two general classes of asphalts and tars.

The asphalts suitable for use as the cementing agent in road construction are produced either by reducing asphaltic base petroleum to a suitable consistency by the distillation process or by softening the so-called solid asphalts to a suitable consistency by the addition of flux produced by the partial distillation of petroleum.

The different grades, relative to consistency, of road oils are usually produced by the partial reduction of asphaltic base petroleum.

By the destructive distillation of bituminous coals or the "cracking" of petroleum oils during the carburetting process in the manufacture of water gas, crude tars are produced. These crude tars are refined or reduced by distillation to a suitable consistency for use in road construction.

Bitumens are used in road construction for the purpose of waterproofing the surface and adding to the mechanical bond of the mineral aggregate by cementing together the finer particles of mineral matter, thus preventing their displacement under the action of traffic and retaining them in the road surface where they fill the interstices between the larger stone and bind them together.

The desirable characteristics of bituminous material for road building purposes are, first, *Adhesiveness*, second, *Non-Susceptibility* to changes in temperature, and third, *Stability* or "life." The chief object of bituminous material specifications is to make imperative these desirable qualities of the material.

In connection with testing bituminous materials the thought should be kept in mind that the laboratory results obtained in the different tests are largely for comparative purposes. By this means new or but little used materials may be compared with materials which have proven satisfactory under service tests. Also laboratory results furnish an accurate means to specify the exact characteristics of the material desired for any given purpose.

Adhesiveness.—The adhesiveness of the material is provided for in specifications by suitable requirements of ductility and toughness.

The ductility and toughness tests are made for the purpose of determining the adhesive and binding qualities of the material under different conditions of temperature. The ductility test is made by determining the distance a briquette of the material, having a standard cross-section (1 sq. cm.) will draw out before breaking. Since temperature effects the results, a standard temperature of 77 degrees Fahrenheit, has been adopted generally for making this test. Experience teaches that the greater the distance that a briquette of the material will stretch out before breaking the more sticky and adhesive the material. This test may be performed in a rough manner by pulling out a small roll of the material between the fingers. Material which will not pull out to a long thread before breaking is usually spoken of as "short." Such materials are not adhesive or sticky and it is extremely difficult to bind a road with them, even under the most favorable circumstances.

As stated, the ductility test is usually made at a temperature of 77 degrees Fahrenheit and thus measures the adhesiveness of the material at a rather high temperature. To obtain an indication of the character of the material at a low temperature the Toughness test is made at a temperature of 32 degrees Fahrenheit. This test is performed by dropping a weight of 2 kilograms on a cylinder of the material 1¾ inches in diameter by 1¾ inches in height. The first height of the drop is usually from a distance of 5 cm. and is gradually increased until rupture of the cylinder occurs. A rough field test for toughness may be performed by noting whether a piece of the material will fracture under a sharp blow. If the temperature of the material is about 32 degrees Fahrenheit, the results will be more indicative of the character of the material.

Bitumens which are brittle or which give a low toughness result, lose their binding value in cold weather and roads constructed by their use are apt to ravel and break up under traffic.

Bitumens which give good ductility and toughness results under the methods outlined, will give satisfactory results as the cementing medium when used in road construction provided the other construction details have been properly followed out.

In connection with the stickiness and adhesiveness of bitumens the fact should always be kept in mind that their purpose in road construction as cementing medium, is most effective when used with a hard, clean, dry mineral aggregate. As the departure from these qualities of the mineral aggregate increased so also are increased the difficulties of getting a satisfactory road surface firmly bound together.

Susceptibility to Changes in Temperature.—The susceptibility to changes in temperature is shown by the relative hardness as indicated by the penetration tests at different temperatures, as 32 degrees Fahrenheit, 77 degrees Fahrenheit and 115 degrees Fahrenheit.

The consistency of asphalts is referred to as the "penetration." The penetration test is made by measuring the distance in hundredths of a centimeter that a standard needle under a stated load, applied

for a stated time, will penetrate into it vertically. These variable factors are usually as follows:

Needle — R. J. Roberts' Parabola "Sharps" No. 2.
at 32° F. 200 gram weight, 1 minute,
at 77° F. 100 gram weight, 5 seconds,
at 115° F. 50 gram weight, 5 seconds.

The material which is the most susceptible to changes in temperature will show the greatest variation in penetration under varying conditions of temperature. Roads constructed by the use of materials which are extremely susceptible to changes in temperature become soft in warm weather, mark easily, have a tendency to rut and become wavy. In cold weather this material becomes very hard and slippery and is apt to be brittle and become chipped from the road surface.

In addition to the general qualities of bitumens which are shown by penetration tests, this test is used in specifications to define within narrow limits the consistency of the material. The consistency limits placed in specifications are governed by the climate and the type of construction to be followed, also the general size of the mineral aggregate to be used. When the penetration method of construction is followed it is necessary to use a relatively soft asphalt in order that it may be incorporated in the road surface. In the mixing types of construction a harder asphalt may be incorporated with the mineral aggregate. The use of a hard asphalt together with a graded mineral aggregate gives a dense wearing surface that does not readily become wavy under traffic.

The information obtained by the penetration test is not readily checked in the field without the aid of laboratory apparatus, but as a general rule bitumens which are suitable for binders are plastic when "worked" in the hands.

Stability.—When the term "Stability" or "Life" is used in reference to bitumens it refers to the quality of the material by which it retains its characteristics, usually as defined by the specifications, over a long period of time. The laboratory tests which indicate this property are the evaporation test, the ratio of the penetration after evaporation to the original penetration, and the flash point

The heating or evaporation test, is made by placing 50 grams of the material in a flat bottomed dish 2 3/16 inches in diameter by 1 3/8 inches in depth. This is placed in an oven maintained at a specified temperature, usually 325 degrees Fahrenheit for a period of 5 hours.

This test may be considered as an accelerated test on the material. In a binder, the percentage lost by weight together with the resulting hardening as shown by the relative penetration, *i.e.*, the ratio of the original penetration to the penetration after evaporation, are indicative of the "life" of the material. The less the evaporation loss and the less the hardening as shown by the relative penetration the greater will be the "life" of the material.

In an oil used for surface application the evaporation test shows the presence and quantity of light oils. This is indicative of the time required for the oil to "set up" after application to the road

surface; the evaporation from the large surface area of the oil as applied to the road being roughly comparable with evaporation from the smallest surface area of the oil exposed at the higher temperature at which the test is made.

The open flash test is made by heating at the rate of about 10 degrees Fahrenheit per minute, a small quantity of the material, approximately 40 grams in a dish of approximately the same size as the dish used for the penetration tests, 2 9/16 inches in diameter by 1 3/8 inches in depth. A small flame from a capillary tube is passed over the surface of the oil at each increase of 5 degrees in temperature.

A slight "puff" or explosion indicates the flash point has been reached. The presence of light oils or distillates is indicated by a low flash point. The flash point together with the evaporation results give an indication as to the methods and materials used in the manufacture of the bitumen which is being tested.

Unless "cut-back" materials are being tested, in which an exceedingly light distillate as naphtha or benzole has been used as the "cut-back" agent, considerable "smoke" will be given off from the sample before the flash point is reached. This feature should be kept in mind when material is being heated for application in the field. Material should never be heated in the field to a point when it smokes profusely, for at such a temperature the material is being "burned" or hardened to such an extent that it loses its adhesiveness and becomes brittle when cold, thus failing to become a binding or cementing agent which binds the mineral aggregate of the road together.

The same "burning" effect on the material is produced by keeping it at a temperature below the "smoking point" for a long period (several hours) as would be produced at a higher temperature for a shorter period of time. This important feature should always be kept in mind when heating material for application in the field.

Such tests as those for water, specific gravity, purity, paraffine, etc. are usually placed in specifications in addition to the tests which govern adhesiveness, non-susceptibility and stability for the purpose of identification of materials used, methods of manufacture, degree of refinement and care used in refining.

The presence of water in bituminous materials causes frothing when heated to a temperature of about 212 degrees Fahrenheit. In addition to the difficulty experienced in heating material containing water, due to the frothing, an even application or distribution to the road of such material is extremely difficult, due to the presence of the froth which is apt to be applied rather than the liquid bitumen.

Tests for specific gravity, purity, paraffine, etc. require laboratory apparatus to get results which indicate qualities of the material. The information obtained by these tests can not be obtained by field tests.

If we assume that a suitable bitumen has been specified and obtained for construction work in which a bitumen is to serve as the

cementing material, the results obtained, relative to the bitumen, will depend upon:

1. Not over-heating (by high temperature or long time) the bitumen.
2. The use of hard, clean, dry stone.
3. Grading of the mineral aggregate to reduce the voids and obtain greater density.
4. Thorough and uniform incorporation of the bitumen with the mineral aggregate.
5. Maximum consolidation, by rolling when laid.

When bituminous materials which may be applied cold are to be applied to a road surface, that surface should first be put in good condition. Surface application treatment is for the purpose of preserving a road which is in good condition and not repairing an uneven road. We do not repair a house by painting it; rather we repair the house and then paint it, in order that it may remain in good condition. An attempt to build up a road wearing surface by the use of bitumens which may be appied cold usually results in a surface which is easily marked, ruts alnd pushes into waves.

Cement.—There are five different classes of cement, Portland, Natural, Pozzolan, Iron Ore, and Magnesia cements. Of these the Portland or Natural is usualy spiecified.

Portland cement is the term lappled to the finely pulverized product resulting from the calcination to incipient fusion of an intimate mixture of properly proportioned argillaceous and calcareous materials, and to which no addition greater than 3 per cent. has been made subsequent to calcination. (Amer. Soc. Testing Materials 1915—page 353.)

Natural cement is the term applied to the finely pulverized product resulting from the calcination of an argillaceous limestone at a temperature only sufficient to drive off the carbonic acid gas. (Amer. Soc. Testing Materials 1915—p. 352.)

Portland cements are usually heavier, stronger, slower setting, and more uniform than the natural cements and are generally used for road structures, such as culverts, retaining walls, etc. Portland cement is practically the only cement used to any extent in the United States at the present time. The few manufacturers of natural cement who were retaining a hold on the market some few years back when the production of Portland cement was expensive, are finding it difficult to compete with this latter product at its present price and quality.

The following is the standard specification for Portland cement as adopted by the American Society of Civil Engineers and the American Society for Testing Materials:

First: Specific gravity. The specific gravity of cement shall not be less than 3.10. Should the test of cement as received fall below this requirement, a second test may be made upon a sample ignited at a low red heat. The loss in weight of the ignited cement shall not exceed 4 per cent.

Second: Fineness. It shall leave by weight a residue of not more than 8 per cent. on the number 100, and not more than 25 per cent. on the number 200 sieve.

Third: Time of Setting. It shall not develop initial set in less than thirty minutes; and must develop hard set in not less than one hour, nor more than ten hours.

Fourth: Tensile Strength. The minimum requirements for tensile strength for briquettes one square inch in cross section shall be as follows and the cement shall show no retrogression in strength within the periods specified:

Age	Neat Cement	Strength
24 hours in moist air		175 lbs.
7 days (1 day in moist air, 6 days in water)		500 "
28 " (1 " " " " 27 " " ")		600 "

One Part Cement—Three Parts Standard Ottawa Sand	
7 days (1 day in moist air, 6 days in water)	200 lbs.
28 " (1 " " " " 27 " " ")	275 "

Fifth: Constancy of Volume. Pats of neat cement about three inches in diameter, one-half inch thick at the center, and tapering to a thin edge, shall be kept in moist air for a period of twenty-four hours.

(*a*) A pat is then kept in air at normal temperature and observed at intervals for at least 28 days.

(*b*) Another pat is kept in water maintained as near 70 degrees F. as practicable, and observed at intervals for at least 28 days.

(*c*) A third pat is exposed in any convenient way in an atmosphere of steam, above boiling water, in a loosely closed vessel for five hours.

These pats, to satisfactorily pass the requirements, shall remain firm and hard, and show no signs of distortion, checking, cracking or disintegrating.

Sixth: Chemical Composition. The cement shall not contain more than 1.75 per cent. of anhydrous sulphuric acid (SO_3), nor more than 4 per cent. of magnesia (MgO).

The methods used in testing cement are standardized in detail and can be obtained in the "Year Book" of 1913, published by the American Society for Testing Materials or Committee report on "Uniform Tests of Cement" of the American Society of Civil Engineers 1912.

CONCRETE MATERIALS

Fine Aggregate.—Fine aggregate for use in concrete should consist of sand free from any deleterious matter. Any sand which shows a coating on the grains should not be used until satisfactorily cleansed by washing.

The following tests are made on sand to determine its suitability for use in different classes of concrete:

1st. Gradation.
2nd. Percentage of voids.
3rd. Percentage of loam or silt.
4th. Compressive or tensile strength in cement mortar.

In order to secure suitable qualities, minimum requirements determined from the above tests should be definitely specified.

The following specifications are now being used by Highway Departments in several of the States:

Sand for use in Portland cement concrete roads shall be of the following gradation: 100 per cent. shall pass a ¼" screen, not more than 20 per cent. shall pass a No. 50 sieve and not more than 6 per cent. shall pass a No. 100 sieve. Sand may be rejected for this class if it contains more than 5 per cent. of loam and silt. Mortar in the proportion of one part of cement to three parts of the sand, shall develop a compressive or tensile strength at least equal to the strength of a similar mortar of the same age, composed of the same cement and standard Ottawa sand.

Sand for use in foundations, culverts, retaining walls, etc. shall not contain more than 8 per cent. of loam and silt. Mortar in the proportion of one part of cement to three parts of the sand, when tested shall develop a compressive or tensile strength of at least 80 per cent. of the strength of a similar mortar of the same age, composed of the same cement and standard Ottawa sand.

Screenings if substituted wholly or in part for the above sand, should meet the following requirements:

They shall be free from dust coating or other dirt. 100 per cent. shall pass a ¼″ screen and not more than 6 per cent. shall pass a No. 100 sieve. Mortar in the proportions of three parts of the screenings or mixed screenings and sand, with one part of cement shall develop a strength equal to a sand for which it is to be substituted.

The best and safest way in the selection of a concrete sand is to have a fair representative sample from the deposit listed. After this is found to meet the requirements, it is necessary to have constant and careful field inspections and tests made as the deposit is worked.

The use of screenings is not advisable on any concrete work, except where a good grade of sand is not available. When used the product must be constantly inspected and tested as it is likely to vary to a considerable degree. Screenings from the softer limestones should not be used as the fine material is apt to "ball" in the mixer.

Sand used for grout in brick and stone block pavement must be fine enough to ensure it getting between the joints of the block, but an excessively fine sand should be avoided as it weakens the grout. Some states and many municipalities require the grout sand to pass a No. 20 sieve and not more than 30 per cent. pass a No. 100 sieve. Such sand should not contain more than 5 per cent. of loam and silt.

Coarse Aggregate.—Coarse aggregate for use in structural concrete should be of hard durable stone gravel or blast furnace slag (see table of tests) free from coating of any kind. For use in concrete pavement, stone and gravel should be hard, tough and absolutely clean. For use in culverts, retaining walls, etc. stone, gravel or slag should be of sound, unweathered material, clean and free from coating. It should not contain more than 10 per cent. of soft stone or shale. Gravel containing a large percentage of thin flat stone should not be used.

For reinforced concrete the size of the stone is usually ½″ to 1″ in order to facilitate the compacting of the concrete between the reinforcing bars or mesh. For plain concrete a mixed size is used ranging from ½″ to 3½″; a scientifically graded stone reduces the amount of mortar required, but the structures in road work are so small that it does not pay to attempt to reduce the voids in this manner and the size that is available is used, varying the proportions of mortar to get a dense product. For extensive concrete pavement of the first class graded sizes are feasible.

The use of slag in concrete is still a debatable matter but if proven to be reasonable will add materially to the source of concrete materials. The latest available tests by the Pittsburgh laboratory with an up to date discussion is quoted as follows:

TESTS OF BLAST-FURNACE SLAG AS COARSE AGGREGATE IN CONCRETE

"[In order to secure definite authoritative data on the use of blast-furnace slag in concrete, a number of leading interests, which either produce or market slag, made a co-operative arrangement with the Pittsburgh Testing Laboratory of Pittsburgh to conduct a series of experiments and tests that would extend ultimately over a period of five years.

"The reports of these tests will be of more than ordinary value, as the care involved in the preparation and testing of the specimens made the tests more expensive than would ordinarily be undertaken by a commercial laboratory, and the results are such as can be obtained only by having a very carefully organized research department.

"Recognizing that these tests are of the utmost value to engineers in acquainting them with the performance of blast-furnace slag in concrete work, the *Manufacturers Record* publishes herewith extracts from the report compiled by the Pittsburgh Testing Laboratory.—EDITOR *Manufacturers Record.*]

"The purpose of this series of tests was to furnish information relative to the use of concrete materials, as follows:

"(1) A comparison of the crushing strengths of air-cooled blast-furnace slag, crushed stone and gravel when used as the coarse aggregate in concrete, tests to be made at the end of 14, 30, 60 and 180 days, 1 year, 2 years, 3 years, 4 years and 5 years.

"(2) To determine the granulometric analysis of the material as received, together with other physical characteristics.

"(3) Determination of the corrosive tendency of sulphur in slag.

"(4) Effect of sulphur and other elements on the durability of concrete up to the age of five years.

"(5) Relative strength and durability of concrete made of high magnesia, low lime slag and low magnesia high lime slag.

"The materials used as the coarse aggregates in these tests were secured from the following localities:

	P. T. L. Mark
Slag: Cleveland Macadam Co., Cleveland, Ohio (from A. S. & W. Co., Central Fur., Cleveland, Ohio)	87410
Slag: Duquesne Slag Products Co., Pittsburgh, Pa. (from C. S. Co., Duquesne, Pa., slag bank)	87420
Slag: Carnegie Steel Co., Pittsburgh, Pa. (from Ohio Works, Youngstown, Ohio)	87430
Slag: Northwestern Iron Co., Mayville, Wis.	87440
Slag: Standard Slag Co., Youngstown, Ohio (from S. F. Co., Sharpsville, Pa.)	87450
Slag: Cleveland Macadam Co., Cleveland, Ohio (from C. F. Co., Cleveland, Ohio)	87470
Slag: Birmingham Slag Co., Birmingham, Ala. (from T. C. & I. Ry. Co., Ensley, Ala.	87480
Slag: Duquesne Slag Products Co., Pittsburgh, Pa. (from E. S. Co., Pottstown, Pa.)	87520
Slag: The France Slag Co., Toledo, Ohio (from T. F. Co., Toledo, Ohio)	87530
Gravel: Allegheny River, from Pittsburgh, Pa.	87460
Trap Rock: from Birdsboro, Pa.	87490
Gravel: from Akron, Ohio	87500
Crushed granite: from Stockbridge, Ga.	87510
Limestone: from Gates City, Ala.	87540
Dolomitic limestone: Kelly Island, from Cleveland, Ohio	87550

It did not seem practicable to screen the fine aggregate and recombine to conform to Fuller's curve, or to use a combination of two or more sands which would make theoretically the best fine aggregate. The material selected was reasonably well graded, and the same sand was used throughout the series of tests, the whole amount being secured at one time from the back channel of the Ohio River, at Neville Island.

"The cement used was Alpha Portland, from Manheim, W. Va. This brand was selected by lot, being drawn from a list of several standard brands of Portland cement. All cement was purchased at the same time and sam-

pled and tested before the preparation of concrete test specimens was begun. The results of these tests are included in the report.

"As the various aggregates were received, they were screened through sieves consisting of iron plates with circular holes of the following diameters: 1¼ inches, 1 inch, ¾ inch, ½ inch and ¼ inch.

"The portions retained on each of the above sieves were stored separately and labeled, to be later recombined to make the coarse aggregate used in the tests.

"In accordance with the specifications, the coarse aggregate was recombined to conform to Fuller's curve. Since the portion of Fuller's curve representing coarse aggregate is a straight line, and since the curve is referred to ordinates, of which the vertical ordinate is divided into equal parts, showing percentages by weight, and the abscissa is divided into equal parts, representing the diameter of the particles in inches, it follows that coarse aggregates, when so recombined, will consist of equal percentages of the four (4) gradings, which increase in size uniformly from ¼ inch to 1¼ inches. All aggregates, therefore, were recombined by weighing equal quantities of the four gradings and shoveling them together, turning them until their appearance showed them to be thoroughly mixed.

"In order to accurately proportion the concrete, the weight per cubic foot of all materials was determined. Since there is no generally accepted method for determining the weight per cubic foot of concrete materials, one was used which had been found in the past to give consistent results. A cubic foot measure was filled loosely with either sand or the recombined aggregate, after which the measure was dropped 10 times on a felt pad one inch thick from a height of three inches. The measure was again filled and smoothed off with a straight edge and weighed. The average of 10 determinations was taken as the weight per cubic foot of the material used. The variation of the individual determinations was usually within five-tenths of 1 per cent. and seldom over 1 per cent. The weight per cubic foot was frequently redetermined, to take into account any drying out of the material. The weight of the cement per cubic foot was taken at 100 pounds, this being in accordance with the generally accepted figures for cement.

"Void determinations were made on the various aggregates after recombining. Each coarse aggregate was thoroughly wet, drained and a cubic foot measure filled and weighed, as given in the method for determining the weight per cubic foot. Water was then slowly added until the measure was level full. From the increase in weight the percentage of voids was computed.

"It was not possible to combine the sand and cement with the slag, gravel and crushed stone, respectively, to strictly conform to Fuller's curve and still have tests which would be comparable with each other on the basis of equal proportions of cement. It was, therefore, necessary to determine the leanest mixture which would produce a dense concrete when using the coarse aggregate having the highest percentage of voids, and then using this mixture for all materials. By this method the same quantity of cement was used to make each specimen, and the test data shows a comparison of the different aggregates under the same conditions.

"The proportions for the mortar were determined by making trial mortars of various proportions of cement and sand and selecting the mixture giving the maximum density as shown by increase in volume of the resulting mortar. After numerous tests, the proportions of 1 part cement and 2 parts sand were found to most nearly fulfill the tests for maximum density of the mortar.

"The coarse aggregates used for these tests varied in weight per cubic foot from 64 to 104.5 pounds, and the percentages of voids from a minimum of 31.85 to 49.2 per cent. Since the percentage of voids in one case was 49, to obtain the maximum density, using this aggregate, the mixture should be almost exactly two parts of mortar and four of coarse aggregate; this proportion would give some excess mortar in all of the other cases.

"The fact that a 1-2-4 mixture is one which is very commonly used—and a large amount of data may be found for comparison—was an additional reason for using it in these tests.

"These proportions by volume having been selected, the equivalent weight each of the materials for these proportions was determined, and throughout the series of tests all materials were weighed, and greater accuracy in proportioning thus obtained. The mixture, however, is by volume, the method of weighing being used only to insure more accurate proportions.

"A quantity of material sufficient to make ten (10) cylinders was mixed at one time, the sand being spread in a flat pile and the cement placed over this. The two materials were turned by two men until the color appeared to be uniform, three or four turnings being required. The coarse aggregate was then shoveled on this material and the whole turned dry three times. During the fourth turn a weighed amount of water was added from a sprinkling can and three (3) additional turnings given the mixture. During the last three turnings small quantities of water were added as needed until a 'quaking consistency' was obtained. In all mixtures an attempt was made to secure the same consistency, regardless of the amount of water used. For this reason, it was not possible to use a mechanical mixer, as the quantity of water is very important, and in mechanical mixing the material may be made too wet and the whole batch spoiled for laboratory purposes. It is noteworthy that care must be used to obtain the correct consistency, and that the addition of 1 pound of water to a 10-specimen mixture would give a consistency too wet, usually described as 'mushy,' and the results of the tests would be unsatisfactory.

"The specimens were made in steel molds 8 inches in diameter by 16 inches high. The concrete was poured into these molds in layers 4 inches thick, and each layer tamped thirty (30) times with a ⅝-inch round rod. After the second and fourth layers the sides were spaded with a large trowel. These cylinders were finally finished at the top by spading with a small trowel to form a smooth upper rim, and a piece of plate-glass placed on top to form a smooth surface. Since the concrete would settle slightly after a few hours, it was necessary to cap the top of the specimen with plaster-of-Paris and cement and again place the plate-glass on the cap to make a smooth surface.

"The specimens were kept in the molds for forty-eight (48) hours and then stored in damp sand for thirty-five (35) days. At the end of this time all specimens were removed and stored in air. Four (4) short pieces of reinforcing steel were embedded in each of two (2) cylinders from every batch.

"These pieces were 3, 6, 9 and 12 inches long, and were cut from ½ inch twisted reinforcing bars furnished by the Carnegie Steel Co., Duquesne heat No. 99439, having the following chemical analysis:

Carbon	20.0	per cent.
Manganese	45.0	per cent.
Phosphorus	0.018	per cent.
Sulphur	0.046	per cent.

"These specimens will be examined at the end of the five-year period to determine the corrosive action of the aggregates.

"(1) It will be noted that one-half of the tests of the slag concrete were made using slag produced by the quick-cooling process, in

Chemical Analyses of Air-cooled Blast-furnace Slag

P. T. L. laboratory number	87410	87420	87430	87440	87450	87470	87480	87520	87530
Silica	35.35	36.72	34.35	31.98	35.74	33.63	35.55	31.53	35.15
Alumina	12.28	12.81	13.55	12.25	11.81	13.41	12.04	12.39	14.11
Iron oxide	0.90	1.50	1.02	2.00	0.38	1.25	0.62	0.50	0.25
Manganous oxide	0.50	0.61	0.71	0.34	0.70	0.40	0.36	0.22	0.43
Titanium oxide	0.40	0.33	0.50	0.30	0.30	0.40	0.40	0.55	0.45
Calcium oxide	40.05	40.98	45.80	31.75	42.65	39.18	41.35	32.78	38.75
Magnesium oxide	8.20	5.14	1.62	19.43	6.18	9.31	8.45	18.24	8.84
Sulphur in calcium sulphide	1.05	1.29	1.10	0.89	1.26	1.03	0.73	0.89	1.11
Sulphur in calcium sulphate	0.52	0.27	0.41	0.27	0.24	0.20	0.50	0.10	0.17
Sulphur in other forms	....	0.12	....	0.07	....	....	0.05	0.18	
Carbon	....	....	....	....	....	....	....	0.62	

TABLE 24.—RESULTS OF PHYSICAL TESTS

Name of Material Used	Weight per Cu. Ft. of Material Used	Per Cent. of Voids in Material Used	Per Cent. Passing Sieve as Received 1¼	1	¾	½	¼	14 Day Tests: Mark on Cylinder	Weight of Cylinder lb.	oz.	Crushing Strength in lb. per sq. in.	Average Crushing Strength in lb. per sq. in.
Slag Cleveland Macadam Co., Central Furnace, Cleveland, Ohio	66.5	49.2	99.35	83.70	48.20	16.10	2.40	9	62	8	1897	1941
								18	62	10	1998	
								29	63	3	1928	
Slag Duquesne Slag Products Co. Duquesne, Pa.	78.5	42.74	96.70	83.70	61.40	32.80	3.50	9	65	10	2212	2159
								18	65	13	2318	
								28	65	8	1946	
Slag Carnegie Steel Co., Youngstown, Ohio	79.3	43.15	97.10	84.10	41.30	11.50	3.50	9	65	4	2346	2134
								18	64	10	2128	
								27	65	4	1928	
Slag Northwestern Iron Co., Mayville, Wis.	64.5	45.87	86.10	65.20	37.30	19.00	1.60	2	62	12	2238	2206
								12	62	12	2141	
								22	63	4	2238	
Slag Standard Slag Co., Sharpsville, Pa.	75.0	41.53	92.40	69.10	40.30	17.80	3.50	2	65	14	2477	2484
								12	65	3	2380	
								28	64	14	2594	
Gravel Allegheny River, Pittsburgh, Pa.	104.5	31.85	80.28	68.38	50.68	30.21	9.45	2	69	2	2045	2046
								12	68	13	2093	
								22	68	11	2000	
Slag Cleveland Macadam Co., Cleveland Furnace Cleveland, Ohio	64.0	46.77	100.0	88.50	57.20	14.50	4.10	2	62	4	2387	2257
								12	62	4	2237	
								22	61	11	2146	
Slag Birmingham Slag Co., Ensley, Ala.	83.8	42.00	98.40	82.80	48.70	15.70	2.90	2	66	13	2043	2109
								10	66	00	2160	
								21	66	10	2126	
Trap Rock Birdsboro, Pa.	98.7	41.93	96.80	87.10	62.80	21.10	2.00	2	72	8	2109	2063
								12	73	1	2053	
								22	72	3	2026	
Gravel Akron, Ohio	95.0	35.9	99.40	88.20	60.30	25.20	3.26	2	68	00	1793	1795
								12	68	7	1800	
								22	67	10	1792	
Crushed Granite Stockbridge, Ga.	90.0	42.34	97.40	84.30	53.50	25.00	5.00	11	69	00	1980	2122
								21	68	00	2178	
								22	69	8	2208	
Slag Duquesne Slag Products Co., Pottstown, Pa.	73.75	43.55	98.62	90.20	70.02	36.09	3.60	1	63	00	2151	2187
								12	64	00	2167	
								22	63	00	2244	
Slag France Slag Co., East Toledo, Ohio	81.75	42.5	90.9	64.90	39.50	29.00	20.00	2	65	13	1918	1942
								12	66	14	1856	
								21	66	10	2051	
Limestone Gates City, Ala.	94.87	40.33	100.0	98.90	83.30	43.40	6.00	1	69	8	1670	1713
								6	69	8	1750	
								7	71	0	1720	
Dolomitic Limestone Kelly's Island, Cleveland, Ohio	94.11	38.71	100.0	96.0	47.00	11.50	3.20	4	69	11	1830	1804
								13	69	7	1814	
								23	69	0	1769	

NOTE.—Above tests carry Pittsburgh Testing Laboratory numbers in consecutive 87500, 87510, 87520, 87530, 87540, 87550.
Compression tests made using 8″ × 16″ cylinders, 1–2–4 Mix—Alpha cement

OF SLAG, STONE, AND GRAVEL USED IN CONCRETE

30 Day Tests					60 Day Tests					180 Day Tests				
Mark on Cylinder	Weight of Cylinder lb.	oz.	Crushing Strength in lb. per sq. in.	Average Crushing Strength in lb. per sq. in.	Mark on Cylinder	Weight of Cylinder lb.	oz.	Crushing Strength in lb. per sq. in.	Average Crushing Strength in lb. per sq. in.	Mark on Cylinder	Weight of Cylinder lb.	oz.	Crushing Strength in lb. per sq. in.	Average Crushing Strength in lb. per sq. in.
10	63	3	2461		8	63	00	2815		7	62	10	3740	
33	63	10	2770	2525	13	62	15	2966	2930	5	62	5	3958	3753
28	62	14	2343		26	62	13	3008		8	63	0	3560	
10	66	00	2425		4	65	6	3143		7	64	12	4280	
17	64	4	2983	2657	13	65	6	3402	3117	16	65	10	4464	4315
27	65	1	2562		22	65	4	2810		25	64	5	4200	
10	65	8	2642		7	66	4	3625		2	65	10	3880	
17	64	00	2568	2657	12	63	10	3220	3306	16	65	00	4130	4154
28	64	10	2761		22	65	12	3074		20	65	5	4452	
3	63	00	2640		5	62	5	3523		1	62	15	4146	
13	62	12	2630	2653	21	63	00	3363	3403	4	62	8	4268	4309
23	63	4	2688		28	62	11	3320		6	63	0	4512	
3	65	00	3127		10	65	11	3359		1	64	11	4906	
13	65	00	2999	3075	18	65	00	3468	3365	5	65	3	4678	4803
27	65	00	3100		21	64	13	3268		9	64	11	4824	
3	68	13	2608		6	68	13	3427		7	68	14	4200	
13	68	9	2514	2510	21	69	2	3170	3295	9	68	9	3816	3969
23	68	15	2409		27	68	13	3289		19	69	1	3892	
1	62	2	2810		3	61	10	3167		6	61	15	4588	
11	61	8	3057	2844	14	62	1	3126	3288	13	61	14	4422	4394
21	62	5	2666		24	61	2	3068		16	61	9	4172	
1	66	9	2660		8	64	00	3270		3	66	2	4432	
11	66	00	2800	2752	17	66	9	3354	3289	4	66	9	4460	4451
20	67	2	2796		25	66	5	3244		7	66	7	4460	
1	72	6	2454		9	72	6	3411		3	72	15	4814	
11	73	5	2330	2386	15	72	12	3416	3360	6	72	12	4738	4819
21	72	9	2374		20	72	8	3256		7	72	14	4906	
1	66	13	2040		8	67	12	2756		3	68	3	3636	
11	67	9	2040	2078	16	68	2	2378	2554	4	68	9	3840	3627
21	67	8	2153		28	67	14	2527		16	68	0	3404	
1	69	00	2230		3	69	2	3112		8	69	6	4190	
12	68	4	2334	2292	16	69	00	2760	3043	17	69	0	4016	4151
22	69	8	2313		19	69	8	3258		23	69	5	4248	
2	64	2	2738		5	63	8	3245		27	63	5	4210	
11	63	6	2600	2650	14	63	00	3244	3289	4	63	6	4203	4184
21	63	00	2613		24	63	8	3378		3	63	0	4140	
1	66	7	2527		7	66	3	3251		3	66	4	4130	
11	65	4	2402	2536	16	66	5	2864	3103	9	66	15	4333	4164
22	66	4	2680		20	66	4	3195		13	65	6	4030	
3	69	9	1985		2	69	6	3149		4	70	0	3936	
10	69	8	1950	1988	15	68	13	3014	3082	8	69	6	4636	4127
23	69	8	2030		22	69	00	3072		9	68	12	3814	
1	69	6	2269		2	70	00	3503		3	70	0	4640	
12	69	14	2442	2360	17	69	12	3846	3604	19	70	0	5011	4724
24	69	00	2375		22	70	12	3462		27	69	0	4520	

order as follows: 87410, 87420, 87430, 87440, 87450, 87460, 87470, 87480, 87490,

selected by lot. Ohio River sand. Large aggregates as shown above.

RESULTS OF PHYSICAL TESTS OF SLAG STONE AND GRAVEL USED IN CONCRETE. AGE OF TEST, ONE YEAR

P. T. L. Laboratory No.	Name of Material Used	Mark on Cylinder	Weight of Cylinder		Crushing Strength in Lb. per Sq. In.	Average
			Lb.	Oz.		
87410	Slag—Cleveland Macadam Co., Central Furnace, Cleveland, Ohio.	2	62	4	4300	4498
		16	62	10	4774	
		7	62	10	4420	
87420	Slag—Duquesne Slag Products Co., Duquesne, Pa.	21	65	..	4824	4725
		5	64	1	4544	
		8	65	11	4808	
87430	Slag—Carnegie Steel Co., Youngstown, Ohio	1	65	8	5092	5028
		5	65	10	5148	
		11	65	6	4844	
87440	Slag—Northwestern Iron Co., Mayville, Wis.	14	62	6	4928	4885
		8	62	2	4556	
		10	62	14	5172	
87450	Slag—Standard Slag Co., Sharpsville, Pa.	6	65	2	5397	5388
		19	64	13	5660	
		17	65	5	5108	
87460	Gravel—Allegheny River, Pittsburgh, Pa.	14	69	3	4556	4627
		11	69	2	4664	
		20	69	3	4660	
87470	Slag—Cleveland Macadam Co., Cleveland Furnace, Cleveland, Ohio.	8	62	12	5152	4956
		23	61	11	4872	
		4	62	1	4844	
87480	Slag—Birmingham Slag Co., Ensley, Ala.	15	66	4	5388	5195
		12	66	3	4748	
		14	65	11	5180	
87490	Trap Rock—Birdsboro, Pa.	4	72	9	4888	4950
		26	73	3	4666	
		14	73	9	5296	

	Gravel—	5	67	4	3790	
87500	Akron, Ohio	9	66	13	3710	3673
		10	67	13	3520	
	Crushed Granite—	6	69	..	4740	
87510	Stockbridge, Ga.	10	68	12	4422	4633
		24	69	2	4738	
	Slag—	18	63	10	4620	
87520	Duquesne Slag Products Co.,	10	63	8	4576	4649
	Pottstown, Pa.	9	63	8	4750	
	Slag—	5	66	.	4972	
87530	France Slag Co.	X	67	2	4794	4787
	East Toledo, Ohio.	4	65	14	4596	
	Limestone—	3	70	..	4340	
87540	Gates City, Ala.	1	69	11	4344	4344
		6	70	12	4348	
	Dolomitic Limestone—	12	69	4	5030	
87550	Kellys Island,	25	69	2	4874	4904
	Cleveland, Ohio.	20	69	12	4808	

NOTE.—Compression tests made, using 8 × 16 cylinders; 1-2-4 mix Alpha cement, selected by lot; Ohio River sand; large aggregate as above.

pits, in which the slag is shipped within a few days from the time it comes from the furnace, and the remainder from slag which had been seasoned in banks for a period of six months in some cases and as much as 15 years in one case.

"(2) The length of time during which this series of tests has been conducted does not warrant the drawing of any definite conclusions, but the general uniformity of the results of the crushing tests of the concrete should be observed.

"(3) Slags coming from furnaces many hundred miles apart, varying quite widely in chemical analyses, and also varying considerably in the weight per cubic foot, do not vary in strength in proportion to either the weight or percentage of any chemical constituent.

Since the following tests were published the one-year test has been completed, and in reporting on these the Pittsburgh Testing Laboratory states:

"In most cases the specimens show a considerable increase in strength over those tested at the age of 180 days, but in some cases the increase is very slight. Discussion of these tests will be withheld until the end of the two or three-year tests, but the discussion of results furnished with the 180-day tests still holds true for these tests. In some instances, as will be noted, an exceptionally high compressive strength has been developed at the age of one year.

Water.—The following quotation from the Concrete Highway Magazine of May, 1918, by Duff A. Abrams shows the effect of excessive water on the strength of concrete. It should be borne in mind that this represents the laboratory point of view but shows very forcibly that excess water is injurious.

"It is commonly stated that concrete is composed of a mixture of cement, sand and pebbles or crushed stones. This conception of concrete overlooks one essential element of the mixture; namely, water. An exact statement of the ingredients of concrete would be: Cement, aggregate, and water. The last-named material has not yet received proper consideration in tests of concrete or in specifications for concrete work.

"Early users of concrete centered their entire attention on the quality of the cement, and practically disregarded the characteristics of the other ingredients. During the past dozen years some attention has been given to the importance of the aggregate, but it is only recently that we have learned that the water also requires consideration.

"A great deal has been said and written recently concerning the effect of water on the strength and other properties of concrete, but the full significance of this ingredient of concrete has not heretofore been pointed out. A discussion which appeared in the April, 1917, issue of the CONCRETE HIGHWAY MAGAZINE gave a brief review of results of some of the experimental work carried out along this line at the Structural Materials Research Laboratory, Lewis Institute, Chicago The relation between the water content and the compressive strength of the concrete for a wide range of consistencies was there pointed out and emphasis was placed on the injurious effect of too much water.

"Tests made in studies of the effect of size and grading of aggregates have shown that the only reason that concrete of higher strength and durability can be produced from well-graded aggregate

as compared with a poorly graded aggregate is that the former can be mixed with less water. If this is not done no advantage is gained from using a coarse, well graded aggregate. The following discussion shows that a similar conclusion can now be stated with reference to a rich concrete mix as compared with a lean one.

"While the injurious effects of too much water in concrete are apparent, tests made in this laboratory show that the truly fundamental rôle played by water in concrete mixtures has been entirely overlooked in previous discussions of this subject. The relation referred to above is brought out by a series of compression tests of about 1600 6 by 12-in. concrete cylinders made up as follows:

Mix Cement-Aggregate	Range of Sizes of Aggregates	Consistency
1–15 1– 9 1– 5 1– 3 1– 2 1– 1 1–1/3 Neat	0–14-mesh sieve 0– 4-mesh sieve 0–1 3/4-inch 0–1 1/2-inch 0–2 -inch	7 different consistencies for each mix and aggregate

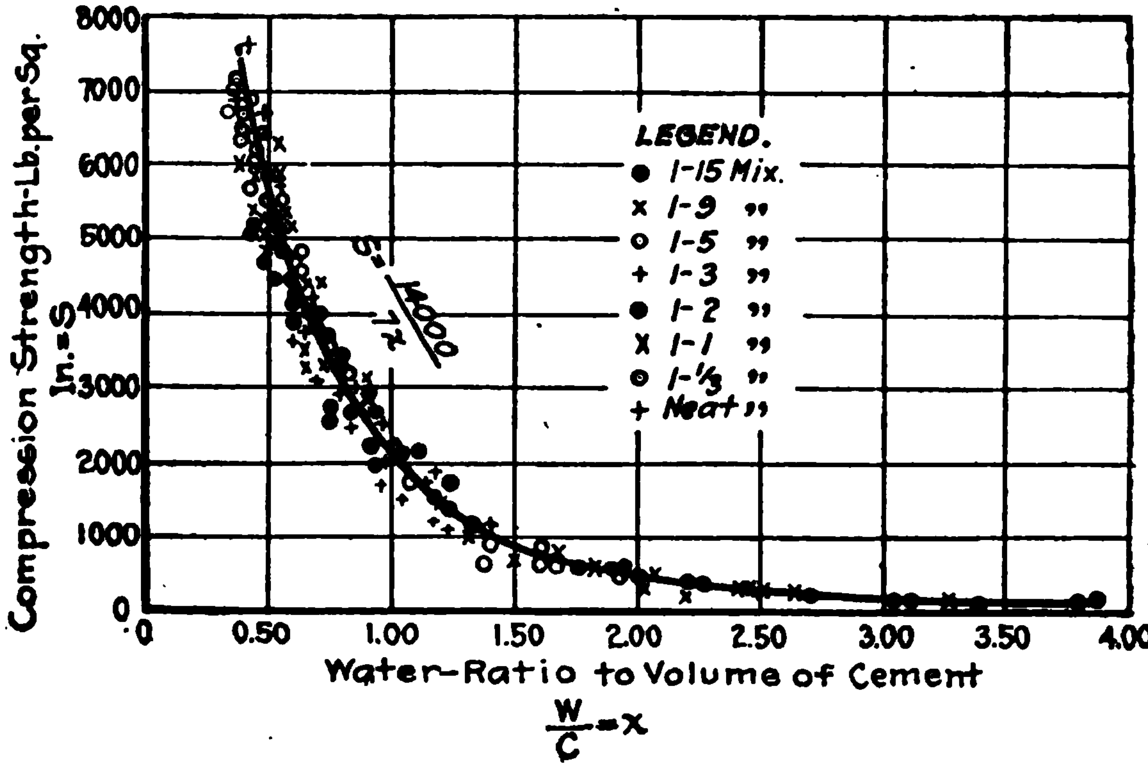
"The mixes used covered a wide range, as did also the grading of aggregate and consistency. The aggregates consisted of two sizes of sand and mixtures of sand and pebbles graded to the sizes shown. The mix is expressed in terms of volumes of dry cement and aggregate, regardless of grading; *i.e.*, a 1 : 5 mix is made up of 1 cu. ft. cement (1 sack) and 5 cu. ft. of aggregate as used, whether a sand or a coarse concrete mixture.

"This series gives valuable information on the effect of changing the quantity of cement, the size of the aggregate and the quantity of water. The effect of many different combinations of these variables can be studied. One set of relations gives the effect of amount of cement using aggregates of different size and grading; another set of relations gives the effect of different quantities of water, varying both mix and size of aggregate, etc. In all respects these tests bear out the indications of both earlier and later series. These tests are of interest in that they reveal for the first time the true relation between the strength and the proportions of the constituent materials in concrete.

"The figure shows the relation between the compressive strength and the water content for the 28-day tests. The water content of the concrete has been expressed as a ratio of the volume of cement, considering that the cement weighs 94 lb. per cu. ft. Distinguishing marks are used for each mix, but no distinction is made between aggregates of different size or different consistencies.

"When the compressive strength is platted against the water in

this way, a smooth curve is obtained, due to the overlapping of the points for different mixes. Values from dry concretes have been omitted. If these were used we should obtain a series of curves dropping downward and to the left from the curve shown. It is seen at once that the size and grading of the aggregate and the quantity of cement are no longer of any importance except in so far as these factors influence the quantity of water required



to produce a workable mix. This gives us an entirely new conception of the function of the constituent materials entering into a concrete mix and is the most basic principle which has been discovered in our studies of concrete.

"The equation of the curve is of the form,

$$S = \frac{A}{B^x} \qquad (1)$$

where S is the compressive strength of concrete and x is the ratio of the volume of water to the volume of cement in the batch. A and B are constants whose values depend on the quality of the cement used, the age of the concrete, curing conditions, etc.

"This equation expresses the law of strength of concrete so far as the proportions of materials are concerned. It is seen that for given concrete materials the strength depends on only one factor—the ratio of water to cement. Equations which have been proposed for this purpose contain terms which take into account such factors as quantity of cement, proportions of fine and coarse aggregate, voids in aggregate, etc., but they have uniformly omitted the only item which is of any importance; that is, the water.

"For the conditions of these tests, equation (1) becomes,

$$S = \frac{14{,}000}{7^x} \qquad (2)$$

"The relation given above holds so long as the concrete is not too dry for maximum strength and the aggregate not too coarse for a given quantity of cement; in other words, so long as we have a workable mix.

"Other tests made in this laboratory have shown that the character of the aggregate makes little difference so long as it is clean and not structurally deficient. The absorption of the aggregate must be taken into account if comparison is being made of different aggregates.

"In certain instances a 1–9 mix is as strong as a 1–2 mix, depending only on the water content. The strength of the concrete responds to changes in water, regardless of the reason for these changes.

"It should not be concluded that these tests indicate that lean mixes can be substituted for richer ones without limit. We are always limited by the necessity of using sufficient water to secure a workable mix. So in the case of the grading of aggregates. The workability of the mix will in all cases dictate the minimum quantity of water that can be used. The importance of the workability factor in concrete is therefore brought out in its true relation.

"The reason a rich mix gives higher strength than a lean one is that a workable concrete can be produced by a quantity of water which gives a lower ratio of water to cement. If an excess of water is used we are simply wasting cement. Rich mixes and coarse, well-graded aggregates, are as necessary as ever, but we now know just how these factors affect the strength of the concrete.

"Practical use may be made of the curve in estimating the relative strength of concretes in which the water content is different for any reason. For example, a concrete mixed with 7.5 gallons of water (1 cu. ft.) to one sack of cement (allowance being made for absorption of aggregate) gave a strength in this series of 2000 lb. per sq. in. ($x = 1.00$). For $x = 0.80$ (6 gal. of water per sack of cement) we have 3000 lb. per sq. in.; for $x = 0.75$ (5.6 gal.) 3300 lb. per sq. in. Concrete in a 1–4 mix (same as the usual 1–2–3 mix with a coarse sand) should be mixed with 5½ to 6 gal. of water per sack of cement.

"The importance of any method of mixing, handling, placing and finishing concrete which will enable the work to be done with a minimum of water is at once apparent. It now seems that practically all faulty concrete work can be traced to the use of too much water.

"Laboratory research performs its true function when it uncovers basic principles which have not been revealed by experience in construction, or observation of completed work."

PART II

PRACTICE OF SURVEY, DESIGN AND CONSTRUCTION

CHAPTER X

PRELIMINARY INVESTIGATIONS

As stated in the introduction the object of all preliminary investigation, either of new locations in unsettled districts or of high type pavement improvements in populous sections, is to secure data on which a reasonable program of work can be based. Work of this kind should be done only by experienced highway engineers as reliable results depend largely on the judgment of engineer which must be based on actual design and construction experience under conditions similar to those investigated. As a rule this portion of the engineering program is carelessly done due to hesitation in spending money before a project is assured but this policy is short sighted as there is no part of the work which is more important.

The cost of first-class investigations of this kind range from $3.00 to $40.00 per mile. A cost of $5.00 to $10.00 per mile is a fair average for long mountain road projects similar in character to the work being done by the U. S. Office of Public Roads in the west and a cost of $5.00 to $15.00 per mile for high type road reports in the eastern states. Reconnaissance surveys in heavily timbered regions may cost as high as $40.00 per mile.

HIGH TYPE ROAD INVESTIGATIONS IN WELL-SETTLED DISTRICTS

The improvement generally consists of betterments to an existing road the location of which is fixed by existing rights-of-way. The choice of which road to improve is made by local boards or the State Highway Commissioner so that when the problem reaches the field engineer his work is confined to a definite engineering report on a definite road.

The field work and report deal with the following main features.

1. *Probable Traffic.*—This forms the basis of decision as to general type (rigid or flexible) and the width of pavement (single or double track).

2. *Local Materials.*—This forms the basis for decision as to the most economical type of pavement of the general class required.

3. *Cost Estimate.*—This forms the basis of appropriations for survey, design, and construction and indicates the mileage that can be completed with the funds at hand.

Field Work.—In any district the volume of traffic is entirely a matter of judgment. A traffic census can be taken but is of little value as the improvement of a road changes the amount and class of travel. The most reliable basis for decision is a study of the map of the locality and inquires of local residents to determine the probable routes of travel for farm traffic to markets or shipping points, for long distance truck traffic, and the location of summer resorts in relation to the improvement, etc. These considerations applied in a comparative way to previously built roads of different types serving districts of practically the same general character form the only reasonable basis for the selection of general type and width. See Chapter VI for traffic classification and the principles of general selection of type. See sample preliminary report page 274 for an example of this part of the work. See page 329 for traffic notes.

Local Materials (Field Work).—The investigation for local material is very important. Careless work in this particular results in specifying impracticable or needlessly expensive sources of supply for materials and often in the selection of an unreasonable type of construction. A careless estimate of the quantity of available local material also causes trouble during construction by a shortage in supply.

It is important not only to determine the amount of local material but also its character as for example a local gravel may be suitable for a first-class bottom for macadam construction but not suitable for a concrete pavement, or it may be suitable for a concrete paving base but not for a concrete road taking the traffic directly. A local hard sandstone may be suitable when bound with bitumen and would not act well if waterbound with its own screenings, etc. The necessary properties of stones, gravels, sands, etc., are given in the Chapter on Materials, and in Specifications.

Any preliminary report should cover the sources of supply and approx. cost at pit or switch of the following materials:

Gravels.—Suitable for..........
- Bottom courses.
- Top courses.
- Structural concrete.
- First-class concrete pavement.
- Concrete paving base.
- Sub-base filler.

Stone, Slag, Etc.—Suitable for
- Sub-base.
- Bottom course.
- Waterbound macadam top.
- Bituminous macadam pavement.
- First-class concrete pavement.
- Concrete paving base.
- Structural concrete.

Sand.—Suitable for............	Bottom course filler. Cushion sand. Structural concrete sand. First-class concrete paving sand. Fine and coarse sand for sheet asphalt.
Miscellaneous..	Bitumens. Tars. Paving brick. Stone block. Asphalt block. Wood block. Stone or brick cubes.
Water Supply.....	Location and quality.

A convenient method of recording the location of materials is as follows:

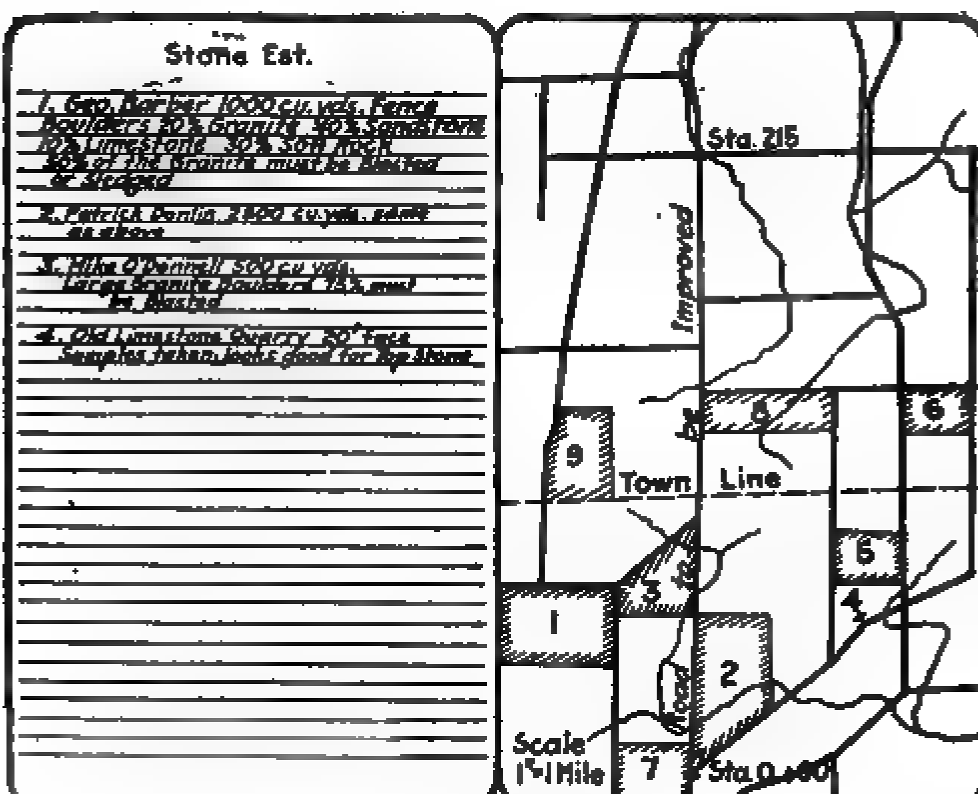


FIG. 59.

Unloading Points for Freight.—Provided U. S. geological maps are obtainable, the position of sidings may be marked on the sheets. The notes for each siding show its car capacity; whether or not an elevator plant can be erected, and if hand unloading is necessary whether teams can approach from one side or two. They should also show any coal trestle that can be utilized in un-

loading and the location and probable cost of any new sidings that will materially reduce the length of the haul. Canal or river unloading points are shown in the same manner.

Sand, Gravel and Filler Material.—The position of sand and gravel pits and filler material are noted with their cost at the pit; if no local material is available the cost, f.o.b. at the nearest siding is given. Samples are taken and tests made.

Stone Supply.—Provided imported stone is to be used the work is simplified to determining the rate, f.o.b. to the various sidings for the product of the nearest commercial stone-crushing plant that produces a proper grade of stone.

In case local stone is available the location of the quarries or outcrops is shown; the amount of stripping, if any, and the cost of quarry rights. If the estimate will depend upon rock owned by a single person an option is obtained to prevent an exorbitant raise in price.

In case of field or fence stone a careful estimate is made of the number of yards of boulder stone available, the owners' names, what they will charge for it, the position of the fences or piles relative to the road, or side roads, and if the fences are not abutting on a road or lane the length of haul through fields to the nearest road or lane. As fences are usually a mixture of different kinds of rock, the engineer estimates the percentage of granite, limestone, sandstone, etc., and the percentage that will have to be blasted or sledged in order to be crushed by an ordinary portable crusher. The amount of field stone required per cubic yard of macadam is given in estimates, page 593. If there is a large excess of stone a careful estimate need not be made, only enough data being collected to determine the probable position of the crusher set-ups and the average haul to each set-up. If a sufficient supply is doubtful a close estimate is made as outlined above, and options obtained from the various owners.

Samples of the different rocks are tested (see "Materials").

Simple field tests can be made but if the department has a testing laboratory it is better to take samples and have a careful test made and recorded. As these tests are made the location of the sample and result of the tests are recorded on a large map of the district which in the course of a few years shows at a glance the different sources of supply of acceptable materials for the entire county or State and saves future duplication of work for reconstruction, maintenance and adjacent improvements.

The method of sampling and the amounts of material required for a good test are quoted below from the New York State Instructions for Sampling Materials.

SAMPLING

Samples of material will be taken by a duly authorized employee of the Department, in its place of occurrence or manufacture or delivery by carrier. These samples must be taken from different parts of the lot of material to be tested, so as to be fairly representative, and must be unmixed with foreign substances and placed in clean and safe receptacles; and they must conform in all respects to the requirements given under the special

headings. They must be carefully and securely packed, enclosing notification slip properly protected from wear and injury, and sent by express "collect" to the "Bureau of Tests, State Highway Commission, Albany, N. Y." a postal card notice being mailed at the same time. Envelopes, scoops, cans, thermometers, etc., for use in taking the samples, may be had from the Bureau of Finance and Audit at Albany.

In the case of materials sampled at place of manufacture, check samples may be required; these are to be taken and treated the same as ordinary samples, except that the packages must be marked "Check Samples," and the use of the material needed not be prohibited pending the results of the check tests.

Sand and Gravel.—The character of the supply, whether from stream bed, bank, crusher bins, etc., is to be stated; also the use for which it is intended, whether for concrete foundations or other structures, binder for waterbound macadam, filler or wearing carpet or blotter for bituminous macadam, or for aggregate in waterbound or bituminous macadam, etc.

Material which will all pass through a ¼ in. screen will be considered sand. Each sample of sand or screenings shall be ¾ cu. ft. in volume; of gravel 1½ cu. ft.

A small sample shall be taken from each test sample sent, and be kept on the contract as a measure of the quality of material.

Each sample is to be shipped in a tight box or in a clean, closely woven bag from which there will be no leakage; the usual identification slip is to be enclosed. In numbering samples, sand and gravel are to be treated as one material, not as two.

Notification of acceptance or rejection may be expected to arrive at the Division office twenty days after the submission of the samples and data, providing the need of a retest does not cause delay.

Cement.—One sample is to be taken from at least every ten barrels or every forty bags, care being taken to properly distribute the sampling over the lot. Each sample shall be not less than 27 cu. in. in volume or enough to fill a 3 in. cube. Whenever possible, samples should be forwarded in envelopes furnished by the Commission for that purpose, the envelopes being filled to the line marked thereon.

The individual samples are not to be numbered, but each group or lot of these samples representing a single boat load or car load is to be given a lot number, and these lot numbers are to run consecutively. Not more than one boat load or car load is to be represented by one lot number.

Receipt of notification of acceptance or rejection of cement sampled at destination may be expected to arrive at the Division Engineer's office twelve days after the submission of the samples and data. If cement is held for twenty-eight day tests the Division Engineer will be notified accordingly.

Concrete.—The concrete on each highway must be sampled for testing, the samples being taken at random from the batches used and being molded at the place and time of mixing. The work need not be delayed pending the results of the tests.

Each sample shall be a pair of cubes measuring 6 in. on the edge or of cylinders 8 in. in diameter and 16 in. long; the sample is to be made in such manner as to fairly represent the concrete going into the structure. At least one sample is to be taken, and as many more as seem to be required by changes in the character of any ingredient or by any other consideration.

In concrete pavement work (whether foundation or top course) one pair of cubes or cylinders should be sent for every 500 cubic yards. Not less than two pairs are to be sent, however small the pavement.

The sample must remain in the mold two days, then be buried in clean sand to age under the same conditions as the material in the structure. On the twenty-first day the samples shall be taken out and shipped.

Each sample is to have its number painted on each piece, and is to be shipped in a box, properly protected from breakage and surface chipping, accompanied by the usual included identification slip and the postal notification. Especially must the class of concrete, the purpose for which it is used (kind of structure and portion), and the date and time of day when sample was mixed, be stated.

Bituminous Material.—When material is shipped in barrels one sample is to be taken for every twenty or twenty-five barrels, the sampling being properly distributed over the lot.

When material is shipped in tank cars one sample is to be taken from

every 2000 or 2500 gallons, the samples being taken from equally distributed levels in the car.

When mineral bitumen is shipped in loose bulk, one sample is to be taken for every five or six tons, the samples being taken from different levels and different locations in the lot and never from the surface of the material.

Each sample shall be not less than 14 cu. in. in volume, which volume is slightly less than one-half pine or about the size of a one pound paint can.

It should be remembered that the bituminous material will flow at summer temperature or thereabouts, and consequently great care should be used in sealing cans and doing up packages. Whenever possible, samples should be forwarded in the cans furnished by the Commission for the purpose.

The individual samples are not to be numbered, but each group or lot representing a single boat load or car load is to be given a lot number, and these lot numbers are to run consecutively; not more than one boat load or car load of material is to be represented by one lot number.

In order to check the weighing and marking of bituminous material shipped in barrels, one unopened barrel out of every car load of approximately 65 barrels, or a proportionate number of barrels for each boat load, is to be selected at random and weighed. The gross weight found, and the gross weight marked on the barrel, are to be entered on the Monthly Bituminous Material Reports or the information may be recorded elsewhere and submitted to the Bureau of Tests. Any noticeable difference between the gallonage marked on a barrel and the gallonage found therein, must be reported to the Headquarters office at Albany.

The unit of measure for bituminous material is the gallon measured at the temperature of 60°F. If the volume of material is measured when hot, allowance should be made for expansion according to the following table, which will apply approximately to all of the different classes of bituminous material at present used on the State highways:

Increase in volume of various classes of bituminous material when heated from 60°F.

To 400°F. is approximately	12 per cent.
To 350°F. is approximately	10 per cent.
To 300°F. is approximately	8 per cent.
To 250°F. is approximately	6 per cent.
To 200°F. is approximately	4 per cent.
To 150°F. is approximately	2 per cent.

Stone.—Rotten or partially disintegrated stone, or weathered specimens from the surface of a quarry or ledge, are not to be submitted.

Samples of quarry or ledge stone must be representative of the sound, fresh, interior stone of the ledge or quarry. Such samples may be secured either by blasting or by breaking up with the sledge. If all material is of the same variety, texture, etc., one sample will suffice. If, however, there are different varieties, separate samples are to be taken of each and report made as to the extent, giving details as to location and position for use.

All field stone, whether in walls, piles, or scattered over the ground, which might be used, must be examined and a representative sample taken. When two or more varieties of great difference in quality or texture are observed to exist, separate samples are to be taken of each, and report made as to the percentage of each kind, the amount of small stone which might run through the crusher without action, and the percentage of disintegrated or badly weathered rock present.

In taking samples from the output of crushers, fifteen pounds of crushed material not smaller than 1½ in. in size shall be taken, and also one piece at least 3 × 4 × 5 in. shall be procured from the source of supply.

Each sample shall weigh not less than twenty-five pounds nor more than thirty-five pounds. If the entire sample submitted is a single piece of stone, it should be remembered that a piece about the size of a man's head will weigh twenty-five or thirty pounds. While not less than twenty-five pounds are absolutely necessary in each sample, care should be taken to see that the samples do not weigh over thirty-five pounds. One piece of each sample shall be at least 3 × 4 × 5 inches.

Each sample is to be given a number running consecutively in each Division. This number must contain both the Division number and the sample number; thus, sample No. 42 from Division No. 1 would be marked "1-42." Paint or Higgins drawing ink may be used to mark directly on the sample, or a label or tag may be securely fastened thereto.

Samples may be shipped in boxes, burlap, grain bags, cement bags, etc. It is preferred that stone be shipped in a strong bag or in a double bag which may be formed by placing one bag inside of another. If shipping in a single bag which the sample only partially fills, the bag should be securely tied just above the sample and the remaining unfilled part of the bag folded back so as to completely envelop the stone and the portion of bag containing it; this folded back part should then be securely tied on the other side of the sample; this makes a tying of the bag on two sides of the stone, and permits two thicknesses of the bag to completely surround the stone, and if securely tied is as satisfactory as a double bag.

Receipt of notification of acceptance or rejection of stone may be expected to arrive at the Division Engineer's office twelve days after the submission of the samples and data, provided acceptance or rejection is not deferred awaiting a retest.

The location of source of supply is to be expressed by an index number according to the system used in the Government Office at Washington, which is, that each quadrangle of the U. S. Geological Survey Sheet is divided into nine sections numbered from 1 to 9 inclusive, as shown in the following plan:

1	2	3
4	5	6
7	8	9

The north and south sides of each section are then divided into 22 spaces designated from A to V and the east and west sides into 32 spaces designated 1 to 32, so that the location of the stone may then be closely defined, as for example, Quadrangle Albany, Section 7, Letter J, Number 13, which when abbreviated would read "Albany-7-J-13."

Paving Brick.—A sufficient number of samples in every case is to be taken to insure the use of brick of proper quality, but it should also be borne in mind that the charges for transportation and testing of brick are high, and only the smallest number of samples necessary for this purpose should be submitted. At least one sample is to be taken from every 200,000 brick or less. Each sample shall consist of 30 bricks.

If in a shipment or several shipments of the same make and kind of brick there appear to be different classes of brick—such as brick of different degrees of burning, for example—a full sample of each class is to be taken.

Each brick selected for the sample is to be free from cracks or other defects which would prevent its passing inspection at the road, for the sample must represent bricks which will not be culled out. Especially is it forbidden that any person financially interested in the manufacture or use of brick be present when samples are taken.

Each sample (consisting of 30 bricks) shall receive a number, the numbers to run consecutively for each road.

The sample shall be shipped in wooden boxes, not more than 10 or 12 bricks being put in one box on account of weight and strength of package.

Notification of acceptance or rejection of brick sampled at destination may be expected to arrive at the Division Engineer's office nine days after submission of samples and data, providing the need of a retest does not cause delay.

Asphalt Block.—A sufficient number of samples in every case is to be taken to insure the use of block of proper quality, but it should also be borne in mind that transportation and testing costs are high, and only the smallest

number of samples necessary should be submitted. At least one sample is to be taken from every 100,000 blocks or less. Each sample shall consist of 2 blocks.

If in a shipment or several shipments of the same make and kind of block there appear to be different classes of block, a full sample of each class is to be taken.

Each block selected for the sample is to be free from every defect that would prevent its passing inspection at the road, for the sample must represent blocks which will not be culled out.

Each sample (consisting of 2 blocks) shall receive a number, the numbers to run consecutively for each road.

The sample shall be shipped in a wooden box, with usual identification card and postal notice.

Notification of acceptance or rejection of block sampled at destination may be expected to reach the Division Engineer's office fourteen days after submission of samples and data, providing the need of a retest does not cause delay.

Acceptance

Upon completion of the testing of any set of samples the Division Engineer is notified of the acceptance or rejection of the material, and transmits the statement to the engineer in charge of the contract.

Estimates of Cost.—The length of the road can be obtained from maps (U. S. G. S. are convenient) or by autometer distances or pacing. Maps are generally available and serve as a convenient basis for notations. A field inspection by one man preferably on foot furnishes the necessary data on required drainage, foundation soils, approximate amount of excavation, condition of existing bridges and all special features.

Minor drainage features can generally be lumped and assumed to run about $700 per mile. (For more detailed cost, estimate each culvert separately. See chapter on "Drainage.") Special bridges must be figured in detail. (See chapter on "Drainage for Standard Design," etc.)

The amount of excavation per mile for ordinary rolling topography is entirely a matter of judgment which can only be developed by personal experience in similar work. For special long hills requiring a cut and fill reduction a rough profile can be run with an Abney level. However the item of excavation on macadam roads rarely exceeds 20% of total cost and considerable error in estimating the yardage will not greatly effect the value of the estimate.

The character of the natural road soil has an important bearing on the depths of macadam and must be carefully recorded. This can best be done by giving the character of the soil; noting whether the improved road will probably be in cut or fill at the points recorded and specifying the recommended depths of macadam. The depths of macadam for different classes and traffic and different soils were indicated in Chapter V, page 152. Sample notes on foundation soils are shown on page 330.

Methods of computing pavement costs are given in Chapter XIV.

The sample preliminary report following illustrates the method to be followed for high type roads. A report of this character will rarely differ from the final cost of construction by more than 15%. While photographs increase the value of these reports

they are not as essential as for new locations. Notes on photography are given in Chapter XII.

PRELIMINARY DESIGN REPORT, NEW CONSTRUCTION

December 10, 1914.

Division Engineer
Dept. of Highways,
Dear Sir:

In accordance with your request on Nov. 25th, find enclosed report on a reasonable cost for the Town Line-Manitou State-County Highway.

General Report and Estimate, Town Line-Manitou State-County Highway

With a proper use of local materials a satisfactory road can be built at a cost of $94,000 or approx. $11,000 per mile including Engineering and Contingencies. An expenditure of $12,000 per mile would not however be excessive.

The Braddocks Bay crossing is the expensive feature of this road; it raises the cost of the entire road about $1000 per mile.

Design No. 1 is recommended (see page 280).

A detail report follows.

Signed,

Designing Engineer.

DETAIL REPORT AND ESTIMATE, TOWN LINE-MANITOU STATE-COUNTY HIGHWAY

Length.—Eight and fifty-one hundredths miles from the Ridge Road to Manitou Beach.

Foundation Soil.—Heavy soil, not particularly good foundation Sta. 0 to 133; sandy soil balance of distance except across Braddocks Bay. A 9 in. thickness of some form of macadam is advisable Sta. 0 to 133; 7 in. or 8 in. the balance of the distance should be satisfactory except across Braddocks Bay where it is safe to figure on 12 in. to 15 in. of stone.

Grade.—The present surface can be followed closely. The excavation should not exceed 2800 cu. yd. per mile except across Braddocks Bay; a rough estimate of borrow excavation for this fill is 15,000 cubic yards.

Alignment.—Good; no right-of-way required except possible at Sta. 350 near the schoolhouse at the turn to Manitou.

Traffic and Section.—There is a heavy volume of automobile pleasure traffic and a light volume of heavy hauling traffic on this road.

The large amount of pleasure travel requires from 16 ft. to 18 ft. of stone surface; the heavy hauling does not require over 12 ft. to 14 ft. full depth metaling. We recommend a graded section 26 ft. to 28 ft. wide between ditches in cut with a 12 ft. width of full depth metal with 6 ft. of extra width of local crusher run on the shoulders Sta. 0 to 133; a 14 ft. width with 4 ft. of stone on shoulders Sta. 133 to 260; a width of 12 ft. of full depth metal with 6 ft. of stone on shoulders the balance of the distance except across Braddocks Bay where the entire width of metaling 16 ft. should have the full depth.

This road carries so much high speed traffic that it requires some form of bituminous macadam or if Waterbound is selected, it should be treated with calcium chloride immediately and have a surface coat of bitumen applied early in the next year.

Railroad Crossings.—Sta. 223 R. W. & O. Ry. crossing; no gates or flagman. In the summer time the crossing should have a flagman as the orchards cut off the view. The crossing is not particularly dangerous, but during the season of the year the traffic on this road is entitled to better protection at this point.

The approach grade from the south should be made easier.

Drainage.—No special features; approximate cost $3500 exclusive of bridges above 5 ft. span to be built by the towns.

Dangerous Places.—The Braddocks Bay crossing is a dangerous one as the fill is high and the swamp is full of semi-fluid muck from 6 ft. to 12 ft. deep; a first-class concrete guard rail protection should be provided.

Materials

Filler Sand.—In abundance along road and from roadbed excavation.

Gravel.—The only good gravel is lake gravel; this can be obtained up to approximately 6000 cu. yd. 1½ miles north of Sta. 350 and 3000 cu. yd. ½ mile west of Sta. 450. Probably this can be used to advantage (screened or selected beach run) as bottom course Sta. 350 to 450 or as filler for sub-base bottom and on the shoulders.

Stone.—Fifteen thousand cubic yards of fence stone are available within a mile and a half of the road Sta. 0 to 133.

There is practically no local stone Sta. 133 to 350. Four thousand cubic yards of fence stone are available within 1½ miles of Sta. 350.

This material runs about 20% granite fit for top and the balance soft sandstone fit for bottom either as a sub-base bottom or crushed stone bottom.

There is sufficient stone at the south end of the road to build a sub-base bottom with crushed stone filler; a local granite top with crushed stone on the shoulders from Sta. 0 to 133 and a local crushed stone bottom 5 in. thick Sta. 133 to about Sta. 200.

There is sufficient stone at the north end to build about 1¾ miles of crushed stone bottom with stone on shoulders or 1½ miles of sub-base bottom with crushed stone filler and crushed stone on shoulders. I do not think there is enough granite to make it worth while to try and use a local top on any part of the north end.

It is probably better to use an imported top from Sta. 133 to 450 and imported bottom Sta. 200 to 280. (See detail Stone Statement and Computations following.)

Crusher Set up at Sta. 100.—Fifteen thousand cubic yards field stone available within 3 miles maximum haul. Average haul 1¼ miles.

Assume for safety that only 11,000 cu. yd. are available with an average haul to crusher of 1 mile.

Of this 11,000 cu. yd. field stone.

3000 cu. yd. used for sub-base bottom average	haul ¼ mile.
1000 cu. yd. used for crushed stone filler	haul to crusher ½ mile. haul from crusher ¾ mile.
700 cu. yd. used for crushed stone shoulders	haul to crusher ½ mile. haul from crusher ¾ mile.
2500 cu. yd. used for top course	haul to crusher 1 mile. haul from crusher ¾ mile.

7200 cu. yd. field stone used for local macadam, from Sta. 0 to 133, leaving 3800 cu. yd. available for crushed bottom and shoulder stone for road north of Sta. 133.

Three thousand eight hundred cubic yards will produce approximately 3000 cu. yd. of crushed bottom loose measure or about 2300 cu. yd. of rolled measure. This will build 10,600 lin. ft. of 5 in. bottom 14 ft. wide. We can therefore safely specify local bottom to Sta. 200 which will leave enough shoulder stone to use as far north as Sta. 300 if necessary.

Crusher Set up at Sta. 350.—Four thousand cubic yards available within 1½ miles say average haul 1 mile.

Assume for safety that 3000 cu. yd. only are available, average haul 1 mile. This will produce about 2400 cu. yd. crushed bottom stone loose measure or approximately 1800 cu. yd. rolled measure. One thousand eight hundred cubic yards will build approximately 90 Sta. of 12 ft. bottom 5 in. deep which makes it safe to specify a local bottom using crushed stone and lake gravel as far south as Sta. 280 with either gravel or crusher run the entire length of road on the shoulders.

Imported bottom should be used Sta. 200 to 280.

Imported Stone.—One dollar and twenty-five cents per ton f.o.b. switch. Switch can be built at Sta. 233 for $300 to $400.

Water.—Can be obtained at all seasons at intervals from 1 mile to 1½ miles all along the road.

Cost of Different Types

Grubbing and clearing	$ 300.00
23,000 cu. yd. roadbed excavation @ $0.50	11,500.00
15,000 cu. yd. brow exc. across Braddocks Bay @ $0.45	6,750.00
800 cu. yd. sub-base @ $1.25	1,000.00
4,000 lin. ft. concrete G. R. across Braddocks Bay @ $1.00	4,000.00
Drainage of system	3,500.00
Minor points @ 400 per mile	3,400.00
Engineering and contingencies	8,000.00
Total cost of items other than metaling	$38,450.00

Schedule of Unit Prices

Imported waterbound top Sta. 133 to 450	$5.00 per cu. yd. rolled
Imported bit. mac. top Sta. 133 to 450	7.30 per cu. yd. rolled
[1]Local granite bit. mac. top Sta. 0 to 133	6.00 per cu. yd. rolled
[1]Imported limestone water mac. Sta. 0 to 133	5.50 per cu. yd. rolled
Sub-base bottom crushed stone filler 0 to 133	1.50 per cu. yd. rolled
Local crushed bottom Sta. 133 to 200	2.50 per cu. yd. rolled
Imported mac. bottom Sta. 200 to 280	3.20 per cu. yd. rolled
Local crushed bottom Sta. 280 to 350	2.30 per cu. yd. rolled
Lake gravel bottom Sta. 350 to 450	1.90 per cu. yd. rolled
Crushed stone or gravel on shoulders	1.50 per cu. yd. loose
Tarvia B	0.08 per gal. in place

Table of Comparative Cost

Type	Approx. Cost Including Eng. and Contingencies	
	Cost per Mile	Total Cost
Design No. 1 (for details see Cost Estimate Sheet)	$11,000	$ 93,500
Design No. 2 (for details see Cost Estimate Sheet)	11,300	96,200
Design No. 3 (for details see Cost Estimate Sheet)	12,000	102,200
Design No. 4 (for details see Cost Estimate Sheet)	12,500	106,000

Computation of Unit Prices

Overhead approximately 30c. per cubic yard of bottom and top stone. No overhead estimated on other items.

Sub-base Bottom Course Crushed Stone Filler Sta. 0 to 133

Cost of stone in fences	$0.10
Loading	0.15
Hauling ¼ mile	0.12
Placing and sledging	0.20
Rolling	0.05
Crushed stone filler. (See Filler) 0.35 cu. yd.	0.40
	$1.02
20% profit	0.20
Overhead	0.30
Estimate	$1.52

Say $1.50

[1] There is no difference in cost Sta. 0 to 133 between a local granite bit. mac. top and an imported limestone waterbound top when treated with Tarvia B.

Crushed Stone Filler (Crusher Run)

	Per Cu. Yd.
Cost of stone in fences	$0.10
Loading	0.15
Haul to crusher 1 mile	0.35
Crushing	0.10
Cost in bins	$0.70
Loading to wagons	0.01
Haul to road ¾ mile	0.22
Spreading and brooming	0.20
	$1.13
0.35 cu. yd. per yard of sub-base =	$0.40

Local Crushed Stone Bottom Sta. 133 to 200

Cost in bins	$0.70
Loading to wagons	0.01
Hauling to road 1¼ miles	0.40
Spreading	0.06
Rolling	0.05
	$1.22
Consolidation 0.3	0.37
	$1.59
Filler	0.20
	$1.79
20% profit	0.36
Overhead	0.30
Say $2.50	$2.45

Stone on shoulders $1.50 per cu. yd. loose.

Local Granite Bit. Mac. Top Sta. 0 to 133

Stone in fences	$0.10
Loading	0.15
Blasting and sledging	0.15
Hauling to crusher	0.35
Crushing	0.15
	$0.90 in bins
Loading to wagons	0.01
Hauling to road ¾ mile	0.22
Spreading	0.06
Rolling	0.08
	$1.27
Consolidation	0.38
	$1.65
Screenings No. 2 and Bit	3.10
Profit	0.90
Overhead	0.30
Estimate	$5.95

Say $6.00

No. 2 Screenings and Bitumen. Note: There should be enough local screenings for about ⅝ of the top course. Use imported for the balance.

Cost 0.45 cu. yd. screenings and No. 2 at bin	$0.40
Hauling ¾ mile	0.10
Spreading	0.12
Manipulation 21 gal. bitumen @ 1½c.	0.32
Cost 21 gal. bitumen on road @ 8½c.	1.82
	$2.74

Imported Screenings and No. 2

Cost 0.45 cu. yd. f.o.b. switch @ $1.25 per ton	$0.70
Unloading	0.05
Hauling 3 miles	0.90
Spreading	0.12
Manipulation 21 gal. bitumen @ 1½c.	0.32
Cost 21 gal. bitumen on road @ 8½c.	1.80
	$3.89

Average price $3.10

Imported Limestone Waterbound Mac. Sta. 0 to 133

Materials:		
4400 lb. of stone @ $1.25 per ton		$2.75
6% profit		0.15
		$2.90
Labor:		
Unloading		$0.10
Hauling 3 miles @ $0.25		0.75
Spreading		0.08
Rolling and puddling		0.10
		$1.03
Consolidation 0.3		0.31
		$1.34
Screenings		0.55
20% profit		0.38
Overhead		0.30
Materials		2.90
Estimate		$5.47
Screenings:		
Unloading	$0.05	
Hauling 3 miles	0.40	
Spreading and brooming	0.10	
	$0.55	

Imported Limestone Waterbound Mac. Sta. 133 to 450

Materials	$2.90
Labor:	
Unloading	0.10
Hauling 90 sta. 1¾ miles	9.55
Spreading	0.08
Rolling and puddling	0.10
	$0.83
Consolidation	0.25
	$1.08
Screenings	0.45
20% profit	0.30
Overhead	0.30
Materials	2.90
Estimate	$5.03
Say $5.00	
Screenings:	
Unloading	$0.05
Hauling 1¾ miles	0.30
Spreading and brooming	0.10
	$0.45

Imported Limestone Bituminous Macadam Sta. 133 to 450

Materials:	
4200 lb. @ $1.25 f.o.b. per ton	$2.62
6% profit	0.15
	$2.77
Labor:	
Unloading	$0.10
Hauling	0.55
Spreading	0.08
Rolling	0.08
	$0.81
Consolidation 0.3	0.24
	$1.05
Screenings and bitumen	$2.52
20% profit	0.70
Overhead	0.30
Materials	2.77
Estimate	$7.34

Screenings No. 2 and Bitumen

Unloading	$0.05
Hauling	0.25
Spreading and brooming	0.12
21 gal. bitumen A. @ 8½c.	1.78
Manipulation of bitumen	0.32
	$2.52

Imported Limestone Bottom Sta. 200 to 280

Materials:	
3200 lb. stone @ $1.25 per ton	$2.00
profit	0.10
Total materials	$2.10
Labor:	
Unloading	$0.10
Hauling average distance, 20 sta.	0.15
Spreading	0.06
Rolling	0.05
	$0.36
Consolidation 0.3	0.11
	$0.47
Filler	0.20
	$0.67
20% profit	0.13
Overhead	0.30
Materials	2.10
	$3.20

Local Stone Mac. Bottom Sta. 280 to 350

Stone in fences	$0.10
Sledging	0.05
Loading	0.15
Hauling to crusher 1 mile	0.35
Crushing	0.12
Cost in bins	$0.77
Loading to wagons	0.01
Haul to road 0.7 mile	0.22
Spreading	0.06
Rolling	0.05
	$1.11
Consolidation 0.3	0.33
	$1.44
Filler	0.20
	$1.64
20% profit	0.33
Overhead	0.30
Say $2.30	$2.27

Lake Gravel Bottom Sta. 350 to 450

Assume ⅛ material from Manitou Beach.
Assume ⅞ material from beach 1½ miles north of Sta. 350.

Selected Beach Run of Gravel

Cost on beach	$0.10
Loading	0.15
Hauling average 2 miles	0.70
Spreading	0.05
Rolling	0.04
Loam and flushing	0.05
	$1.09
Consolidation 0.2	0.22
	$1.31
20% profit	0.26
Overhead	0.30
	$1.87

Say $1.90

Approximate Cost Estimates

Design No. 1.

Sec. No. 1	12′ wide 6″ sub-base 3″ bit. mac., local top 6′ of stone on shoulders. Treated with Tarvia B or No. 4 road oil. Sta. 0 to 133.
Sec. No. 2	14′ wide 5″ local mac. bot. 3″ waterbound imported limestone top. Treated with Tarvia B. 4′ stone on shoulders. Sta. 133 to 200.
Sec. No. 3	14′ wide 5″ imported bottom; same top as from Sta. 133 to 200 Sta. 200 to 260. 4′ stone on shoulders.
Sec. No. 4	12′ wide 5″ imported bottom 3″ water imported top Tarvia B. 6′ of stone on shoulders. Sta. 260 to 280.
Sec. No. 5	12′ wide 5″ local mac. bottom 3″ water imported top Tarvia B. 6′ stone on shoulders. Sta. 280 to 310.
Sec. No. 6	16′ wide 9″ sub-base bottom 3″ water mac. top Tarvia B. No stone on shoulders. Sta. 310 to 335.
Sec. No. 7	12′ wide 5″ local mac. bottom 3″ water mac. top Tarvia B. 6′ of stone on shoulders. Sta. 335 to 350.
Sec. No. 8	12′ wide 5″ lake gravel bottom 3″ water mac. top Tarvia B. 6′ of gravel or stone on shoulders. Sta. 350 to 450.

	Approximate Amount
Sec. 1. *Sta.* 0 *to* 133	
3000 cu. yd. 6″ sub-base bottom @ $1.50	$4500.00
1500 cu. yd. 3″ bit. mac. (local) top @ $6.00	9000.00
730 cu. yd. stone on shoulders (loose) @ $1.50	1100.00
3500 gal. Tarvia B on stone shoulders @ $0.08	280.00
Sec. 2. *Sta.* 133 *to* 200	
1450 cu. yd. 5″ local mac. bottom @ $2.50	$3625.00
870 cu. yd. 3″ imported waterbound top @ $5.00	4350.00
270 cu. yd. stone on shoulder @ $1.50	405.00
5400 gal. Tarvia B @ $0.08	430.00
Sec. 3. *Sta.* 200 *to* 260	
1300 cu. yd. 5″ imported bottom @ $3.20	$4150.00
780 cu. yd. 3″ imported water mac. top @ $5.00	3900.00
240 cu. yd. stone on shoulders @ $1.50	360.00
4800 gal. Tarvia B @ $0.08	385.00
Sec. 4. *Sta.* 260 *to* 280	
370 cu. yd. 5″ imported bottom @ $3.20	$1185.00
230 cu. yd. 3″ imported water mac. top @ $5.00	1150.00
110 cu. yd. stone on shoulders @ $1.50	165.00
1600 gal. Tarvia B @ $0.08	130.00
Sec. 5. *Sta.* 280 *to* 310	
560 cu. yd. 5″ local bottom @ $2.30	$1290.00
340 cu. yd. 3″ water mac. top @ $5.00	1700.00
170 cu. yd. stone on shoulders @ $1.50	255.00
2400 gal. Tarvia B @ $0.08	190.00
Sec. 6. *Sta.* 310 *to* 335	
1130 cu. yd. 9″ sub-base bottom @ $1.75	$1980.00
380 cu. yd. 3″ water mac. top @ $5.00	1900.00
1800 gal. Tarvia B @ $0.08	145.00
Sec. 7. *Sta.* 335 *to* 350	
280 cu. yd. 5″ local bottom @ $2.30	$ 645.00
170 cu. yd. 3″ water mac. top @ $5.00	850.00
80 cu. yd. stone on shoulders @ $1.50	120.00
1200 gal. Tarvia B @ $0.08	95.00
Sec. 8, *Sta.* 350 *to* 450	
1900 cu. yd. 5″ lake gravel bottom @ $1.90	$3,600.00
1150 " " 3″ water mac. top @ $5.00	5,750.00
550 " " gravel on shoulders @ $1.50	825.00
8000 gal. Tarvia B. @ $0.08	640.00
Totals	$55,100.00
Items other than metal	38,450.00
Total estimates	$93,550.00

Design No. 2. Same widths and foundation construction as Design No. 1 except that a 2½″ imported limestone bituminous macadam is substituted for the 3″ waterbound top treated with Tarvia B.

Cost of 3″ water mac. top Design No. 1	$19,600.00
Cost of Tarvia B. on mac. top Design No. 1	1,500.00
Total	$21,100.00
Cost of 2½″ bit. mac. top	23,800.00
Increased cost Design No. 2 over No. 1	$ 2,700.00

Design No. 3. 16′ road entire distance local bottom Sta. 0 to 200 and 280 to 450 and imported bottom Sta. 200 to 280 with 3″ imported waterbound macadam treated with 0.4 gal. Tarvia B. or 0.25 gal. No. 4 Road Oil.

9,200 cu. yd. local bottom 5″ thick @ $2.25	$20,700.00
1,970 " " imported bottom 5″ thick @ $3.20	6,300.00
6,700 " " imported top 3″ thick @ $5.10	34,200.00
32,000 gal. Tarvia B. @ $0.08	2,560.00
	$63,760.00
Items other than metaling	38,450.00
	$102,210.00

Design No. 4. Substitute a 2½" bit. mac. top for the 3" waterbound top of Design No. 3. This increases the cost approx. $4,000.

Signed,
Designing Engineer.

PRELIMINARY INVESTIGATIONS FOR ROADS IN UNSETTLED DISTRICTS

Reports of this nature can not be figured as accurately as for high type roads but if carefully done should not vary over 25% from the final construction cost. The cost of preliminary investigations depends very largely on the character of the country, the methods employed, and the travel necessary to get to the work and will range from $2 to $40 per mile. A fair average cost for work similar to that done by the U. S. Office of Public Roads in the mountainous districts of the west is $5 per mile for ordinary cases and $30 per mile for a plane table sketch survey in difficult country.

Ordinary Preliminary Investigations.—The improvement to be investigated generally consists of a combination of betterments of existing roads with a large percentage of relocation of the old road or the new location of a highway where no road of any kind traverses the territory. The length of these projects range from 5 miles to 150 miles. The engineer generally receives orders to report on the best general route and approximate cost of a road between definite terminals which requires more general investigation than called for in the preliminary reports on high type roads previously discussed.

The field work is usually made by one or two men on foot or horseback. All possible different routes are examined. As a rule this general examination eliminates all but one or two possibilities which are examined with care; sufficient notes, photographs, etc., being taken to make a reasonably close estimate of cost.

The selection of general route is based on a comparison of the following factors for the different routes.

1. Best location for the development of the country.
2. Longest open season for use.
3. Least rise and fall.
4. Feasible ruling grades.
5. Length and cost.

The following engineering equipment will cover all requirements for obtaining the general data and the detailed information required for a reasonably close cost estimate.

- 2 Aneroid barometers 2½" or 3" dial in leather carrying cases. Tested for range of altitude needed.
- 1 Abney level reading to degrees and per cent.
- 1 Pocket compass 2" floating card dial or, if desired,
- 1 Prismatic compass (card dial preferred).
- 1 4A Kodak with folding tripod.
- Note books, existing maps, etc.

In rolling topography it makes no difference in which direction the line is traced but where elevation is developed on a ruling grade the work should be done from the highest point down hill.

Where aneroid elevations must be depended on considerable care must be exercised. If one aneroid can be left at a stationary point and its fluctuations read at intervals during the day very accurate results can be obtained when the field aneroid is corrected for the fluctuations but this is not feasible for work of this kind as a rule and aneroid elevations are to say the least uncertain. Where used two instruments should be carried; when reading they should be held horizontal and the crystal rapped sharply with the finger nail to free the needle if caught which often happens. Any important elevations should be determined at least twice and a return trip made to the original datum point to check the instrument.

The general rise and fall can be determined by the aneroids.

The approximate location of the road for different ruling grades can be traced with the Abney level.

A rough traverse can be run with the pocket compass or prismatic compass.

Distances can be obtained by pacing (pedometer or hand counter) by timing if on horseback; by scaling from reliable maps or by autometer if on an existing road.

Cross-sections are determined by the Abney level and are taken and recording at sufficient intervals to show the general slope of the sidehill.

Classification of excavation and the cut slopes at which excavation will stand depends on the judgment of the engineer but must be systematically recorded.

Drainage should be carefully estimated particularly the larger structures as this item forms a large percentage of the cost of low type roads.

Clearing and grubbing is recorded by section.

Each engineer has his own ideas about notes and it makes little difference how the data is recorded so long as it is clearly and definitely set down in such a way that anyone can retrace the route and reestimate the cost without additional field work.

The main faults of reports and notes are that they are not sufficiently clear on facts; they generally run strong on generalities and judgment and are not worth the paper they are written on if the author is not available to explain in detail.

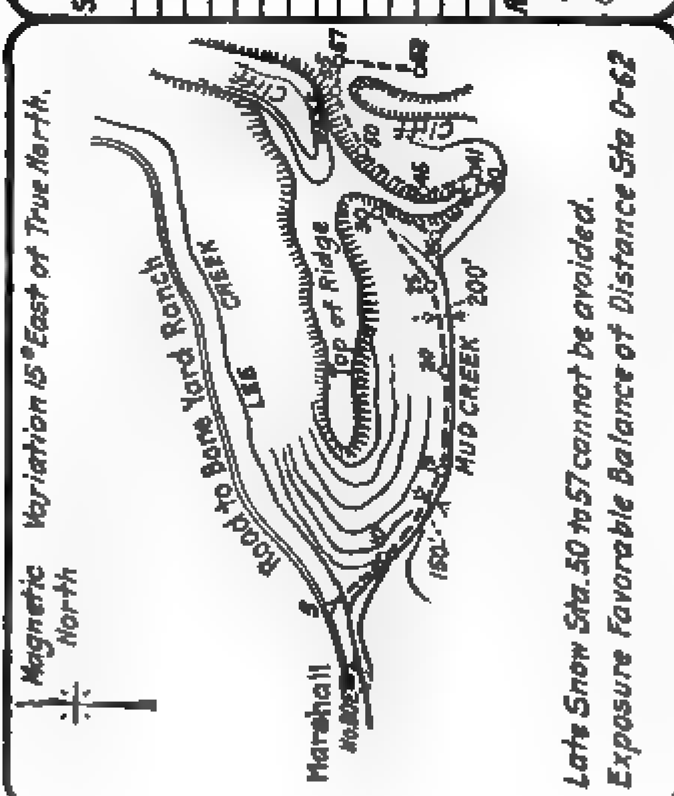
A well arranged report should either summarize the conclusions at the beginning and explain in detail later or be indexed so that the conclusions can be readily located. A preliminary estimate should be rounded out to even figures as amounts figured to single yards or costs figured to odd figures of less amount than 10% of the total cost are merely ridiculous and show that the estimator has lost track of the relative accuracy of his work.

The following form of notes serve in a satisfactory way when supplemented by photographs, sketches and text descriptions.

Detail suggestions on photography are given in Chapter XII.

Table 25 and 26, pages 286 and 296, serve to give a rough approximation of the amount of excavation required.

Drainage costs can be estimated on the standard structures required by the State or Government for whom the work is being



Notes on the Marshall Wind Cave Road.

Sta. to Sta	Bearing.	Profile Grade.	Side Slope.	Classification	Cut Slope.	Aneroid Elev.	Drainage
0 – 5	N. 80° E.	+ 1%	5°	Earth	1½:1	9000	18" Pipe
5 – 10	S. 20° E.	+ 5%	15°	Earth & Boulders	1:1	9020	10' Br.
10 – 15	S. 25° E.	+ 7%	20°	" "	1:1	9050	2(12" Pipe)
15 – 20	S. 60° E.	+ 7%	25°	" "	1:1	9090	4x4 Box
20 – 25	N. 60° E.	+ 7%	35°	" "	1:1	9130	2(15" Pipe)
25 – 30	N. 45° E.	+ 7%	50°	Rock Ledge	¼:1	9160	——

REMARKS: Survey made July 15, 1918 in Company with Louis Igenton Forest Ranger. Distances paced Elevation of Marshall assumed 9000.

Clearing Sta. 0 – 15 Light Sage Brush.
15 – 30 Scrub Oak.
30 – 62 Thick Scrub Oak

Fig. 60.

done or can be approximated by reference to the various standard structures and costs shown in Chapter III and Table 28, page 298. Various miscellaneous information convenient for preliminary estimates are given on page 297. A rough approximation of magnetic declination can be determined from the isogonic charts, pages 302 to 308.

Explanation of Table 25

NOTE.—Quantities determined graphically using one way crown for single track roads on all cross slopes; the 2 way crown for double track roads on cross slopes of 5°, 10° and 15° and the one way crown on cross slopes above 15°.

If for any reason it is desired to use a two way crown on single track roads for cross slopes below 15° reduce the quantities shown in the table by about 25%. For the use of a two way crown above 15° cross slope, special computations will have to be made.

To illustrate the use of this table we will figure the approximate excavation for the notes shown in Figure 60, page 284.

From Sta. 0 to 5 the natural side or cross slope of the ground is given as 5°. In this case a turnpike section can be used say T-12. Turn to page 286 and under section T-12 for a 5° cross slope we find the excavation given as 33 cu. yd. per 100′ or 165 cu. yd. for 500 ft. We will increase this 20% according to judgment for profile inequalities which gives us 200 cu. yd. earth excavation from Sta. 0 to 5.

From station 5 to 10 we have a 15° cross slope. Suppose we are figuring an estimate for a minimum width single track road S-10 look on page 287 and for a cross slope of 15° and a cut slope of 1 : 1 the table gives 46 cu. yd. per 100 ft. or 230 cu. yd. for 500 ft. Increase this by say 20% for inequalities in profile which gives us 276 cu. yd. Estimate the percentage of this classed as rock say 10% and we have 250 cu. yd. for common exc. and 26 cu. yd. of solid rock.

In a similar way estimate Sta. 10 to Sta. 20.

From Sta. 20 to Sta. 25 the notes record a ground cross slope of 35°. This calls for a retaining wall section, see page 293, section W-8 for a 35° cross slope. The table gives the following quantities for 100′.

55 cu. yd. of wall masonry.
100 cu. yd. of excavation.

Multiply this by 5 for 500 feet, add a percentage for inequalities of profile and estimate per cent. of solid rock.

From Sta. 25 to Sta. 30 the notes show a rock ledge with a face slope of 50°. This calls for a section benched out of the solid ledge. See page 294, use Section S-8 the minimum single track section for a cross slope of 50° which gives 350 cu. yd. Rock excavation per 100′ or 1750 cu. yd. for 500 feet.

If turnout sections for passing rigs are desired figure the excess quantities by referring to the parts of the table dealing with the double track widths.

TABLE 25.—BALANCED TURNPIKE SECTIONS USING T-12, T-16 AND T-20

NOTE.—Add from 10 % to 50 % to the following quantities for inequalities in profile requiring through cuts and fills. These sections are recommended only when the natural cross ground slope is 4° or less.

NATURAL GROUND SURFACE CROSS SLOPE		APPROXIMATE EXCAVATION PER 100′ AND PER MILE FOR T-12, T-16 AND T-20					
		Section T-12		Section T-16		Section T-20	
Degrees	Per Cent.	Cu.yd. per 100′	Cu.yd. per mile	Cu.yd. per 100′	Cu.yd. per mile	Cu.yd. per 100′	Cu.yd. per mile
Level	0%	20 cu. yd.	1050 cu. yd.	24 cu. yd.	1250 cu. yd.	35 cu. yd.	1850 cu. yd.
5°	9%	33 " "	1750 " "	41 " "	2150 " "	59 " "	3100 " "
10°	18%	66 " "	3500 " "	90 " "	4800 " "	115 " "	6100 " "

NOTE.—For light scraper work of this kind 1.3 yd. of excavation are assumed to make 1 cu. yd. of fill. This ratio is used in computing the balanced sections in this table.

Table of Approximate Quantities Balanced Sidehill Sections Mountain Roads Using Section S-10

NOTE.—Add from 10% to 50% to the following quantities for inequalities in profile due to the alignment not exactly following the grade contour. An addition of 25% is normally about right for moderately rough country. Good judgment in this matter can only be developed by comparing the results obtained from this table with actual finished location designs.

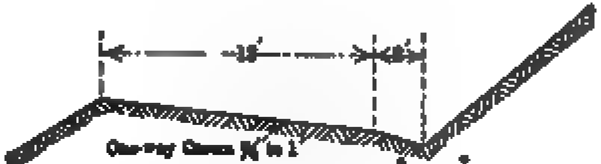
Natural Ground Cross Slope Deg.	Natural Ground Cross Slope Per Cent.	Cut Slope	Fill Slope	Cu. yd. per 100'	Cu. yd. per mile	Cut Slope	Fill Slope	Cu. yd. per 100'	Cu. yd. per mile	Cut Slope	Fill Slope	Cu. yd. per 100'	Cu. yd. per mile	Cut Slope	Fill Slope	Cu. yd. per 100'	Cu. yd. per mile	Cut Slope	Fill Slope	Cu. yd. per 100'	Cu. yd. per mile	Cut Slope	Fill Slope	Cu. yd. per 100'	Cu. yd. per mile
5°	9%	1½:1	1½:1	18	980	1¼:1	1½:1	17	900	1:1	1½:1	16	850	¾:1	1½:1	14	740	½:1	1¼:1	13	690	¼:1	1:1	12	630
10°	18%	1½:1	1½:1	34	1800	1¼:1	1½:1	31	1650	1:1	1½:1	30	1600	¾:1	1½:1	26	1400	½:1	1¼:1	22	1150	¼:1	1:1	21	1100
15°	27%	1½:1	1½:1	53	2800	1¼:1	1½:1	49	2600	1:1	1½:1	46	2400	¾:1	1½:1	42	2200	½:1	1¼:1	35	1850	¼:1	1:1	27	1450
20°	36%	1½:1	1½:1	90	4800	1¼:1	1½:1	80	4200	1:1	1½:1	70	3700	¾:1	1½:1	63	3300	½:1	1¼:1	49	2550	¼:1	1:1	42	2250
25°	47%	...	...	...	...	1¼:1	1½:1	137	7200	1:1	1½:1	115	6100	¾:1	1½:1	97	5100	½:1	1¼:1	70	3700	¼:1	1:1	59	3150
30°	58%	...	...	...	...	...	...	...	...	1:1	1½:1	200	10800	¾:1	1½:1	155	8200	½:1	1¼:1	104	5500	¼:1	1:1	80	4250
35°	70%	...	...	...	...	...	...	...	...	...	...	...	...	...	...			½:1	1¼:1	155	8200	¼:1	1:1	100	5300
40°	84%	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	¼:1	1:1	155	8200

As a general rule a retaining wall section should be used when the natural ground surface cross slope exceeds 30°, except for a solid rock fill which can be used up to a 40° slope.

These balanced sections are computed on the basis that 1.2 cu. yd. of earth excavation will make 1.0 cu. yd. of fill.

Where the cut slopes will stand ½:1 or ¼:1 we have assumed that there is sufficient rock so that 1.0 cu. yd. of excavation will make 1.0 cu. yd. of fill allowing for some rock waste that will occur.

Table of Approximate Quantities Balanced Sidehill Sections Mountain Roads Using Section S-12 (Single Track)



Section for Side Slopes of 5° to 40°

Note.—Add from 10 % to 50 % to the following quantities for inequalities in profile due to the alignment not exactly following the grade contour. An addition of 25 % is normally about right for moderately rough country. Good judgment in this matter can only be developed by comparing the results obtained from this table with actual finished location designs.

Natural Ground Cross Slope		Approximate Excavation per 100′ and per Mile for Different Cut and Fill Slopes (S-12)																							
Deg.	Per Cent.	Cut Slope	Fill Slope	Cu. Yd. per 100′	Cu. Yd. per Mile	Cut Slope	Fill Slope	Cu. Yd. per 100′	Cu. Yd. per Mile	Cut Slope	Fill Slope	Cu. Yd. per 100′	Cu. Yd. per Mile	Cut Slope	Fill Slope	Cu. Yd. per 100′	Cu. Yd. per Mile	Cut Slope	Fill Slope	Cu. Yd. per 100′	Cu. Yd. per Mile	Cut Slope	Fill Slope	Cu. Yd. per 100′	Cu. Yd. per M
5°	9 %	1½:1	1½:1	20	1100	1¼:1	1½:1	18	980	1:1	1½:1	17	900	¾:1	1½:1	15	790	½:1	1¼:1	13	690	¼:1	1:1	12	630
10°	18 %	1½:1	1½:1	41	2200	1¼:1	1½:1	40	2100	1:1	1½:1	38	2000	¾:1	1½:1	35	1850	½:1	1¼:1	27	1450	¼:1	1:1	25	1350
15°	27 %	1½:1	1½:1	68	3600	1¼:1	1½:1	66	3500	1:1	1½:1	63	3300	¾:1	1½:1	60	3100	½:1	1¼:1	46	2450	¼:1	1:1	41	2200
20°	36 %	1½:1	1½:1	120	6300	1¼:1	1½:1	105	5500	1:1	1½:1	94	5000	¾:1	1½:1	85	4500	½:1	1¼:1	65	3400	¼:1	1:1	60	3200
25°	47 %	....	....	....	....	1¼:1	1½:1	180	9500	1:1	1½:1	145	7700	¾:1	1½:1	130	6900	½:1	1¼:1	94	5000	¼:1	1:1	78	4100
30°	58 %	....	....	....	....	....	....	....	....	1:1	1½:1	270	14200	¾:1	1½:1	210	11100	½:1	1¼:1	145	7700	¼:1	1:1	110	5800
35°	70 %	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	½:1	1¼:1	220	11600	¼:1	1:1	140	7400
40°	84 %	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	....	¼:1	1:1	215	11400

Note.—The apparent discrepancy in relative quantities of Sections S-12 and S-14 for side slopes of 5°, and 15° is due to the use of the one way crown for these slopes on single track roads and the two way crown for double track roads.

As a general rule a retaining wall section should be used when the natural ground surface cross slope exceeds 30°, except for a solid rock fill which can be used up to a 40° slope.

These balanced sections are computed on the basis that 1.2 cu. yd. of earth excavation will make 1.0 cu. yd. of fill

Where the cut slopes will stand ½:1 or ¼:1 we have assumed that there is sufficient rock so that 1.0 cu. yd. of excavation will make 1.0 cu. yd. of fill allowing for some rock waste that will occur.

TABLE OF APPROXIMATE QUANTITIES BALANCED SIDEHILL SECTIONS MOUNTAIN ROADS USING SECTION S-14 (Double Track)

Section for 5° to 15° Slopes   Section for 15° to 40° Slopes

NOTE.—Add from 10% to 50% to the following quantities for inequalities in profile due to alignment not exactly following the grade contour. An addition of 25% is normally about the right value for moderately rough country.

Natural Ground Cross Slope		Approximate Excavation per 100′ and per Mile for Different Cut and Fill Slopes (S-14)																							
Deg.	Per Cent.	Cut Slope	Fill Slope	Cu. Yd. per 100′	Cu. Yd. per Mile	Cut Slope	Fill Slope	Cu. Yd. per 100′	Cu. Yd. per Mile	Cut Slope	Fill Slope	Cu. Yd. per 100′	Cu. Yd. per Mile	Cut Slope	Fill Slope	Cu. Yd. per 100′	Cu. Yd. per Mile	Cut Slope	Fill Slope	Cu. Yd. per 100′	Cu. Yd. per Mile	Cut Slope	Fill Slope	Cu. Yd. per 100′	Cu. Yd. per Mile
5°	9%	1½:1	1½:1	20	1100	1¼:1	1½:1	18	950	1:1	1½:1	17	900	¾:1	1½:1	15	790	½:1	1¼:1	13	690	¼:1	1:1	12	630
10°	18%	1½:1	1½:1	41	2200	1¼:1	1½:1	38	2000	1:1	1½:1	35	1900	¾:1	1½:1	33	1700	½:1	1¼:1	24	1300	¼:1	1:1	22	1200
15°	27%	1½:1	1½:1	75	4000	1¼:1	1½:1	68	3600	1:1	1½:1	63	3300	¾:1	1½:1	55	2900	½:1	1¼:1	45	2400	¼:1	1:1	40	2200
20°	36%	1½:1	1½:1	150	7900	1¼:1	1½:1	132	7000	1:1	1½:1	115	6100	¾:1	1½:1	105	5600	½:1	1¼:1	85	4500	¼:1	1:1	78	4100
25°	47%	.....	.....	.	.....	1¼:1	1½:1	220	11700	1:1	1½:1	190	10200	¾:1	1½:1	163	8600	½:1	1¼:1	118	6200	¼:1	1:1	96	5100
30°	58%	.....	.....	...	.....	.....	.....	...	.....	1:1	1½:1	370	19600	¾:1	1½:1	300	15800	½:1	1¼:1	185	9800	¼:1	1:1	137	7200
35°	70%	.....	.....	...	.....	.....	.....	...	.....	...	.....	...	.....	.....	.....	..	...	½:1	1¼:1	275	14600	¼:1	1:1	180	9500
40°	84%	.....	.....	.	...	.....	.....	...	.....	...	.....	...	.....	.....	.....	...	.....	.....	.....	.	....	¼:1	1:1	270	14300

As a general rule a retaining wall section should be used when the natural ground slope exceeds 30°, except for solid rock fill which can be used up to 40° slope.

These balanced sections are computed and balanced on the basis that 1.2 cu. yd. of excavation will make 1 cu. yd. of fill.

Where the cut slopes will stand at ½:1 or ¼:1 we have assumed that 1 cu. yd. of excavation will make 1 cu. yd. of fill allowing for rock waste that will probably occur.

Table of Approximate Quantities Balanced Sidehill Sections Mountain Roads Using Section S-16

Section for 5° to 15° Slopes

Section for 15° to 40° Slopes

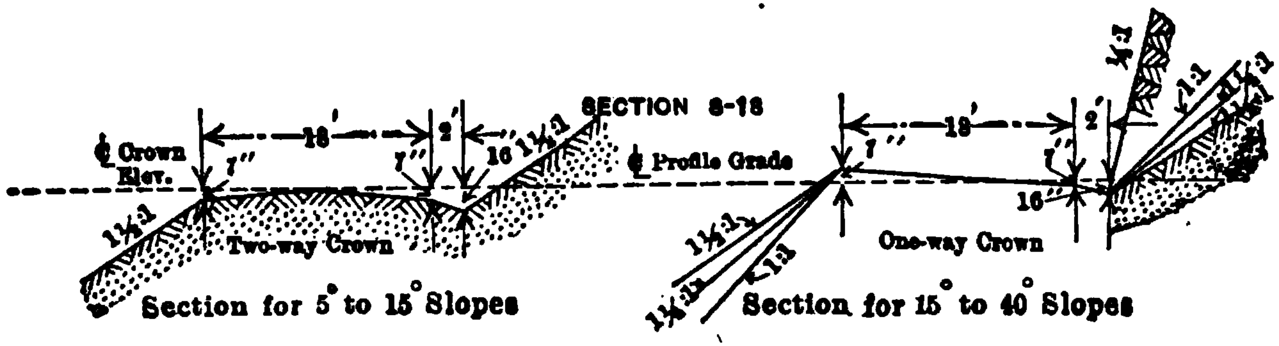
NOTE Add from 10% to 50% to the following quantities for inequalities in profile due to alignment not exactly following the grade contour. An addition of 25% is normally about right for moderately rough country. Good judgment in this matter can only be developed by comparing the results obtained from this table with actual finished location designs.

Natural Ground Cross Slope		Approximate Excavation per 100′ and per Mile for Different Cut and Fill Slopes (S-16)																							
Deg.	Per Cent.	Cut Slope	Fill Slope	Cu. Yd. per 100′	Cu. Yd. per Mile	Cut Slope	Fill Slope	Cu. Yd. per 100′	Cu. Yd. per Mile	Cut Slope	Fill Slope	Cu. Yd. per 100′	Cu. Yd. per Mile	Cut Slope	Fill Slope	Cu. Yd. per 100′	Cu. Yd. per Mile	Cut Slope	Fill Slope	Cu. Yd. per 100′	Cu. Yd. per Mile	Cut Slope	Fill Slope	Cu. Yd. per 100′	Cu. Yd. per Mile
5°	9%	1½:1	1½:1	27	1430	1¼:1	1½:1	26	1380	1:1	1½:1	25	1330	¾:1	1½:1	24	1270	½:1	1¼:1	19	1000	¼:1	1:1	18	950
10°	18%	1½:1	1½:1	54	2850	1¼:1	1½:1	51	2700	1:1	1½:1	47	2500	¾:1	1½:1	44	2300	½:1	1¼:1	32	1700	¼:1	1:1	30	1600
15°	27%	1½:1	1½:1	95	5000	1¼:1	1½:1	89	4700	1:1	1½:1	82	4300	¾:1	1½:1	75	4000	½:1	1¼:1	62	3300	¼:1	1:1	56	3000
20°	36%	1½:1	1½:1	195	10300	1¼:1	1½:1	170	9000	1:1	1½:1	150	7900	¾:1	1½:1	137	7200	½:1	1¼:1	106	5600	¼:1	1:1	92	4850
25°	47%	.....	.....	...	......	1¼:1	1½:1	292	15400	1:1	1½:1	241	12800	¾:1	1½:1	200	10600	½:1	1¼:1	150	7800	¼:1	1:1	125	6600
30°	58%	.....	.....	...	......	.....	.....	...	......	1:1	1½:1	466	24600	¾:1	1½:1	368	19500	½:1	1¼:1	230	12100	¼:1	1:1	166	8800
35°	70%	.....	.....	...	......	.....	.....	...	......	.....	.....	...	......	.....	.....	...	......	½:1	1¼:1	365	19300	¼:1	1:1	227	12000
40°	84%	.....	.....	...	......	.....	.....	...	......	.....	.....	...	......	.....	.....	...	......	.....	.....	...	......	¼:1	1:1	350	18500

As a general rule a retaining wall section should be used when the natural ground slope exceeds 30°, except for solid rock fill which can be used up to 40° slope.

These balanced sections are computed and balanced on the basis that 1.2 cu. yd. of excavation will make 1 cu. yd. of fill. Where the cut slopes will stand at ½:1 or ¼:1 we have assumed that 1 cu. yd. of excavation will make 1 cu. yd. of fill allowing for rock waste that will probably occur.

Table 25.—Approximate Quantities Balanced Sidehill Sections Mountain Roads Using Section S-18



Note.—Add from 10% to 50% to the following quantities for inequalities in profile due to alignment not exactly following the grade contour. An addition of 25% is normally about right for moderately rough country. Good judgment in this matter can only be developed by comparing the results obtained from this table with actual finished location designs.

Natural Ground Cross Slope		Approximate Excavation per 100′ and per Mile for Different Cut and Fill Slopes (S-18)																							
Deg.	Per Cent.	Cut Slope	Fill Slope	Cu. Yd. per 100′	Cu. Yd. per Mile	Cut Slope	Fill Slope	Cu. Yd. per 100′	Cu. Yd. per Mile	Cut Slope	Fill Slope	Cu. Yd. per 100′	Cu. Yd. per Mile	Cut Slope	Fill Slope	Cu. Yd. per 100′	Cu. Yd. per Mile	Cut Slope	Fill Slope	Cu. Yd. per 100′	Cu. Yd. per Mile	Cut Slope	Fill Slope	Cu. Yd. per 100′	Cu. Yd. per Mile
5°	9%	1½:1	1½:1	33	1750	1¼:1	1½:1	33	1750	1:1	1½:1	32	1700	¾:1	1½:1	32	1700	½:1	1¼:1	27	1430	¼:1	1:1	26	1380
10°	18%	1½:1	1½:1	67	3500	1¼:1	1½:1	64	3400	1:1	1½:1	60	3200	¾:1	1½:1	56	2950	½:1	1¼:1	41	2200	¼:1	1:1	38	2000
15°	27%	1½:1	1½:1	115	6200	1¼:1	1½:1	110	5800	1:1	1½:1	102	5400	¾:1	1½:1	94	5000	½:1	1¼:1	80	4200	¼:1	1:1	72	3800
20°	36%	1½:1	1½:1	240	12700	1¼:1	1½:1	210	11100	1:1	1½:1	185	9800	¾:1	1½:1	170	9000	½:1	1¼:1	128	6800	¼:1	1:1	107	5700
25°	47%	...	...	...	...	1¼:1	1½:1	365	19400	1:1	1½:1	292	15400	¾:1	1½:1	242	12800	½:1	1¼:1	185	9800	¼:1	1:1	150	7800
30°	58%	...	...	...	...	...	...	...	...	1:1	1½:1	563	29800	¾:1	1½:1	435	22900	½:1	1¼:1	278	14700	¼:1	1:1	195	10300
35°	70%	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	½:1	1¼:1	455	24100	¼:1	1:1	274	14500
40°	84%	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	¼:1	1:1	425	22500

As a general rule a retaining wall section should be used when the natural ground slope exceeds 30°, except for solid rock fill which can be used up to 40° slope.

These balanced sections are computed and balanced on the basis that 1.2 cu. yd. of excavation will make 1 cu. yd. of fill. Where the cut slopes will stand at ½:1 or ¼:1 we have assumed that 1 cu. yd. of excavation will make 1 cu. yd. of fill allowing for rock waste that will probably occur.

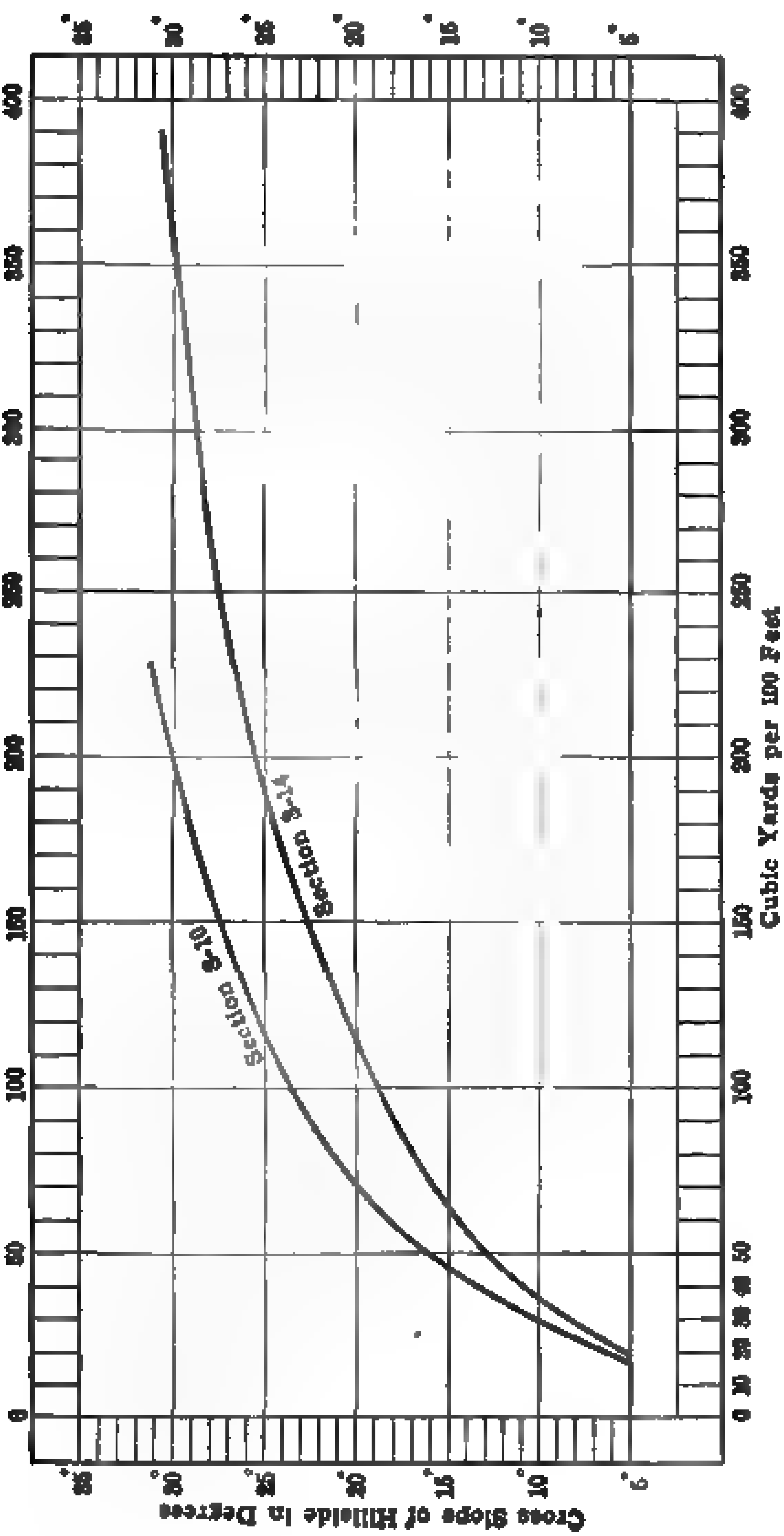
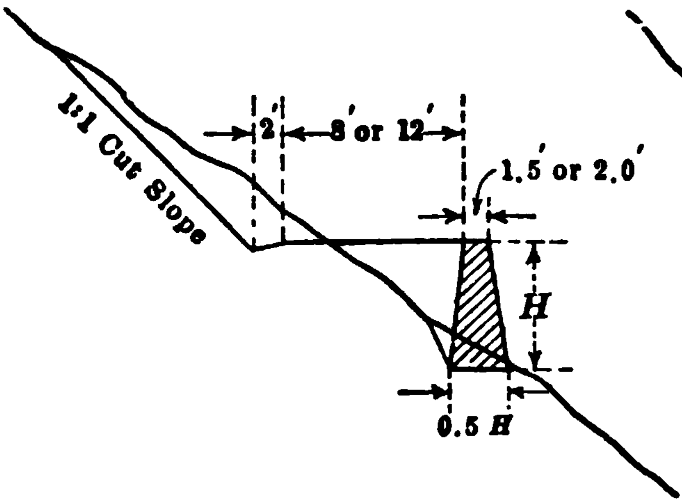


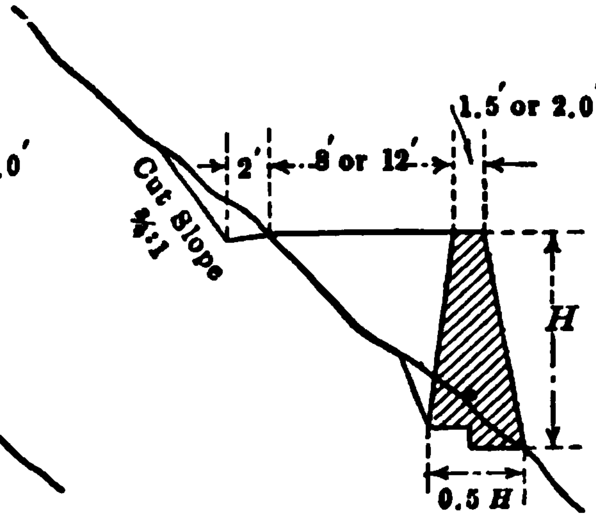
Diagram showing Excavation for Sections S-10 and S-14

Cut Slope 1:1
Fill " 1½:1

TABLE 25.—APPROXIMATE QUANTITIES WALL SECTION MINIMUM
SINGLE TRACK ROAD SECTION W-8
DOUBLE " " " W-12



TYPICAL SECTIONS
30° & 35° Slopes
Ditch Excavation Makes
Fill Back of Wall



TYPICAL SECTIONS
40 & 45 Cross Slopes
Borrow Fill Required

NOTE.—Rough rubble masonry walls to have outside face batter of 3″ to 1′ and a bottom width of ½ the height. The foundation to be carried to a firm strata.

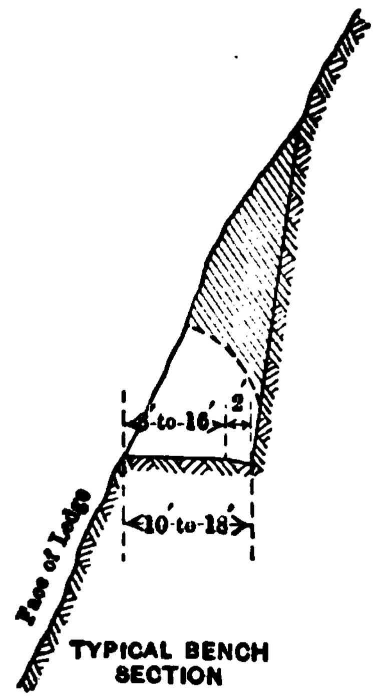
Natural Ground Cross Slope	Approximate Quantities per 100′ of Road for W-8 Section				
	Wall Masonry	Ditch Excavation Used in Fill	Borrow Excavation for Balance of Fill	Wall Excavation Waste	Total Excavation
*30°	46 cu. yd.	55 cu. yd.	None	15 cu. yd.	70 cu. yd.
35°	55 " "	80 " "	None	20 " "	100 " "
40°	100 " "	30 " "	90 cu. yd.	35 " "	155 " "
45°	135 " "	45 " "	100 " "	45 " "	200 " "

TABLE FOR MINIMUM DOUBLE TRACK SECTION W-12

Natural Ground Cross Slope	Approximate Quantities per 100′				
	Wall Masonry	Ditch Excavation Used in Fill	Borrow Excavation for Balance of Fill	Wall Excavation Waste	Total Excavation
*30°	65 cu. yd.	100 cu. yd.	None	15 cu. yd.	115 cu. yd.
35°	90 " "	140 " "	None	20 " "	160 " "
40°	180 " "	30 " "	200 cu. yd.	45 " "	275 " "
45°	250 " "	45 " "	250 " "	80 " "	375 " "

NOTE.—Above 45° ground slope use Rock Bench Sections, except in unusual cases.
* Retaining wall section on 30° cross slope is not usually economical.

TABLE 25.—TABLE OF APPROXIMATE QUANTITIES ROAD BENCHED OUT OF ROCK



Using S-8, S-10, S-12, S-14, S-16

Natural Slope of Face of Rock Ledge	Cut Slope	Approximate Excavation in Cu. Yd. per 100′ for Different Sections				
		*S-8	S-10	**S-12	S-14	S-16
50°	¼ : 1	350 cu yd	500 cu yd	660 cu yd	870 cu yd	1,100 cu yd
60°	¼ : 1	600 " "	850 " "	1,200 " "	1,550 " "	2,000 " "
70°	Vertical	560 " "	800 " "	1,050 " "	1,400 " "	1,800 " "
80°	Half Tunnel	460 " "	550 " "	680 " "		

* Minimum width single track in rock.
** Minimum width double track in rock.

TABLE 26.—APPROXIMATE AMOUNTS OF EMBANKMENT AND EXCAVATION FOR DIFFERENT CENTER LINE CUTS AND FILLS GROUND SURFACE ASSUMED LEVEL

(See page 295.)

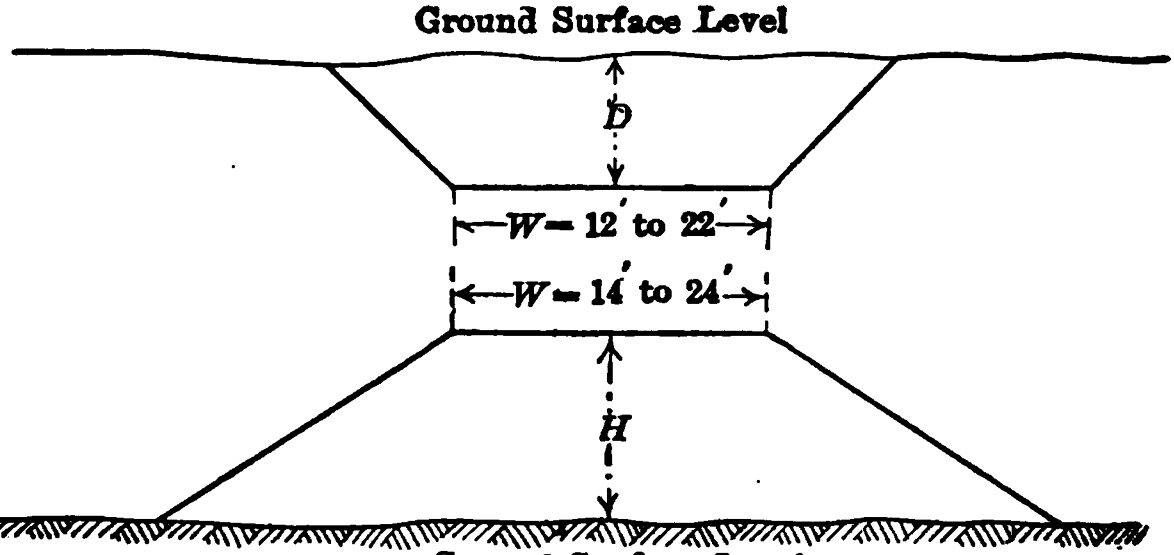


TABLE 26.—APPROXIMATE YARDAGE PER 100 FEET FOR CUT SECTIONS

Center Line Cut in Feet D	W = 12′		W = 14′		W = 16′		W = 18′		W = 20′		W = 22′	
	Cut Slope 1½:1	Cut Slope 1:1	Cut Slope 1½:1	Cut Slope 1:1	Cut Slope 1½:1	Cut Slope 1:1	Cut Slope 1½:1	Cut Slope 1:1	Cut Slope 1½:1	Cut Slope 1:1	Cut Slope 1½:1	Cut Slope 1:1
0.5	24	23	27	27	31	30	35	34	38	38	42	42
1.0	50	48	57	55	65	63	72	70	80	78	87	85
1.5	79	75	90	86	101	97	112	108	124	120	135	131
2.0	111	104	126	119	141	134	156	149	170	163	185	178
2.5	146	134	164	152	183	171	201	189	220	208	238	226
3.0	183	167	205	189	228	212	250	234	272	256	294	278
3.5	224	201	250	227	276	253	302	279	328	305	354	331
4.0	266	237	296	267	325	296	355	326	385	356	414	385
4.5	312	275	345	308	379	342	412	375	445	408	479	442
5.0	361	315	398	352	435	389	472	426	510	463	546	500
6.0	467	400	511	444	556	489	600	533	645	578	689	622
7.0	583	492	635	544	687	596	738	647	790	699	842	751
8.0	711	592	770	651	830	711	889	770	948	829	1007	888
9.0	850	699	916	766	982	832	1050	900	1116	966	1183	1033
10.0	1000	814	1074	888	1148	962	1222	1036	1296	1110	1370	1184
12.0	1333	1067	1422	1156	1511	1245	1600	1334	1689	1423	1778	1512
14.0	1711	1348	1815	1452	1919	1556	2023	1660	2127	1764	2231	1868
16.0	2133	1660	2251	1778	2369	1896	2488	2015	2607	2134	2726	2253
18.0	2600	2000	2733	2133	2866	2266	3000	2400	3133	2533	3266	2666
20.0	3111	2370	3259	2518	3407	2666	3555	2814	3703	2962	3852	3111

TABLE 26.—APPROXIMATE YARDAGE PER 100 FEET FOR FILL SECTIONS

Center Line Fill = H in Feet	W = 14′	W = 15′	W = 16′	W = 17′	W = 18′	W = 19′	W = 20′	W = 21′	W = 22′	W = 23′	W = 24′	W = 26′
	Fill Slope 1½:1	Fill Slope 1½:1	Fill Slope 1½:1	Fill Slope 1½:1	Fill Slope 1½:1	Fill Slope 1½:1	Fill Slope 1½:1	Fill Slope 1½:1	Fill Slope 1½:1	Fill Slope 1½:1	Fill Slope 1½:1	Fill Slope 1½:1
0.5	27	29	31	33	35	37	38	40	42	44	46	50
1.0	57	61	65	69	72	76	80	84	87	91	95	102
1.5	90	95	101	106	112	118	124	129	135	140	146	157
2.0	126	134	141	149	156	164	170	178	185	193	200	215
2.5	164	173	183	192	201	210	220	229	238	247	256	275
3.0	205	216	228	239	250	261	272	283	294	305	316	339
3.5	250	263	276	289	302	315	328	341	354	367	380	406
4.0	296	310	325	340	355	360	385	400	414	429	444	474
4.5	345	362	379	396	412	429	445	462	479	496	513	546
5.0	398	416	435	453	472	490	510	528	546	564	582	620
6.0	511	533	556	578	600	622	645	667	689	711	733	778
7.0	635	661	687	712	738	764	790	816	842	868	894	945
8.0	770	800	830	860	889	919	948	978	1007	1037	1067	1126
9.0	916	949	982	1015	1050	1083	1116	1149	1183	1216	1250	1317
10.0	1074	1111	1148	1185	1222	1259	1296	1333	1370	1407	1444	1518
12.0	1422	1466	1511	1555	1600	1644	1689	1733	1778	1823	1867	1956
14.0	1815	1867	1919	1971	2023	2075	2127	2179	2231	2284	2336	2439
16.0	2251	2310	2369	2429	2488	2547	2607	2666	2726	2785	2844	2963
18.0	2733	2800	2866	2933	3000	3067	3133	3200	3266	3333	3400	3533
20.0	3259	3333	3407	3481	3555	3629	3703	3777	3852	3926	4000	4148

Miscellaneous Information of Value in Making Preliminary Investigations and Estimates

Conversion Per Cent. of Grade to Degrees of Vertical Angle

(For use in tracing grade with transit or Abney Level)

Per cent.	Degrees
1	0° 35′
2	1° 09′
3	1° 43′
4	2° 18′
5	2° 52′
6	3° 26′
7	4° 00′
8	4° 35′
9	5° 09′
10	5° 43′
11	6° 17′
12	6° 51′
13	7° 24′
14	7° 58′
15	8° 32′

Table 27.—Table of Acres Per Station of 100 Feet and Per Mile for Different Widths of Clearing or Right-of-way

Width of Strip	Acreage	
	Per 100′	Per Mile
30 ft	0.069 acres	3.636 acres
40 "	0.092 "	4.849 "
50 "	0.115 "	6.061 "
60 "	0.138 "	7.273 "
70 "	0.161 "	8.485 "
80 "	0.184 "	9.697 "
90 "	0.207 "	10.909 "
100 "	0.230 "	12.121 "

Range in Unit Estimate Prices

Clearing and Grubbing.

Sage brush	$ 10 to $ 50 per mile
Light clearing	$ 20 " $ 60 per acre
Medium clearing	$ 60 " $150 " "
Heavy clearing	$150 " $300 " "

Excavation.

Common.

Machine turnpiking .... $0.15 to $0.25 per cu. yd.
Wheel scrapper and machine finish .... $0.25 " $0.35 " " "
Wagon haul and machine finish .... $0.40 " $0.60 " " "
Side hill plow, scrapper and machine .... $0.35 " $0.75 " " "

Disintegrated Rock or Dry Hard Clay.

Considerable hand work or shooting .... $0.75 " $1.00 " " "

Solid Rock.

Blasting open cut, per cu. yd. $0.80 " $2.00 " " "
Tunnel work .... $4.00 " $5.00 " " "

Retaining Walls.

Rough dry rubber masonry $1.00 " $3.00 " " "
Mortar rubber .... $4.00 " $8.00 " " "

Concrete .... $6.00 " $20.00 " " "

Timber and Lumber .... $30.00 " $80.00 " " "

Carpenter Work.

Simple structures .... $5.00 " $10.00 " M ft. B.M.
Truss framing, etc. .... $10.00 " $20.00 " " "

TABLE 28.—APPROXIMATE COST PER FOOT OF LENGTH SMALL DRAINAGE STRUCTURES

Size of Opening	Kind of Structures: Vitrified Pipe	Corrugated Metal Pipe	* Cast Iron Pipe	** Concrete Boxes	Log Culverts
12″	$0.60	$1.25	$2.00		
15″ or 16″	0.90	1.50	2.90		
18″	1.10	1.80	3.40		
24″	2.00	2.75	5.50		
36″	3.75	4.00	....		
48″	....	6.50	....		
2′ × 2′	....	....	....	3.75	$1.50
2′ × 3′	....	....	....	4.80	1.70
3′ × 3′	....	....	....	5.40	2.30
3′ × 4′	....	....	....	6.00	2.80
4′ × 4′	....	....	....	6.75	3.00
4′ × 5′	....	....	....	8.00	3.60
5′ × 5′	....	....	....	8.70	4.00

* Based on $50 per ton in place.
**Based on $10 per cubic yard in place.

Culvert Data.—Local conditions must be considered in prices of materials, haul, etc., for a close estimate.

Table 50, page 559, gives weights of corrugated pipe.

Table 49, page 558, gives weights of cast iron pipe.

Quantities of concrete can be figured from standard designs given in Chapter III.

Timber in superstructures can be figured from standard designs in Chapter III.

The summarized data shown in Table 28 will however act as a rough guide.

Amounts of masonry in two abutments and four wings for various heights of abutment for small span timber bridge superstructures with 16′ Roadway.

H = height from bottom of foundation to bridge seat.

H in Feet	Cubic Yards	
	Concrete	Masonry
6	24 cu. yd.	29 cu. yd.
7	32 " "	38 " "
8	40 " "	49 " "
9	52 " "	60 " "
10	62 " "	74 " "
12	90 " "	105 " "
14	133 " "	153 " "
16	180 " "	200 " "
18	230 " "	260 " "
20	295 " "	325 " "

Compiled from Plate 29, page 119.

Approximate amount of timber in small span stringer bridge superstructures having 16′ roadway and figured to carry a 20 ton load.

(Figured from Plate 21, page 104)

Clear Span	Feet B. M.	Pounds Hardware
6 ft.	1000	70 pounds
8 "	1400	90 "
10 "	1700	110 "
14 "	2500	130 "
18 "	3300	150 "

NOTE.—For timber spans 30′ to 50′, see Plates 22 and 23, pages 107 to 108.

Pile abutments can be figured from Plate 21, page 104.

Net Volume of Logs in Board Measure.—A convenient approximate rule for computing the net number of feet board measure of sawed timbers in logs is as follows:

$$\frac{\text{Diameter in inches} \times \text{radius in inches}}{12} = \text{Feet (board measure) per foot of log.}$$

Example.

Suppose you have a log 10′ long 12″ in diameter.

$$\frac{\text{Diameter} \times \text{radius}}{12} = \text{number of feet B. M. per foot of log.}$$

$$\frac{12 \times 6}{12} = 6 \text{ ft. B. M. per ft.} \times 10' = 60 \text{ ft. B. M.}$$

Steel Bridges.—The following diagrams taken from various sources will serve as a basis for rough estimates on longer span steel highway bridges. They are figured for a live load of 100 lb. per square foot and presumably for a plank floor. They are of much lighter construction than called for on heavy traffic roads where solid floors and a heavier loading are gaining favor.

Magnetic Declination.—The following isogonic charts give the approximate magnetic declination for States east and west of the Mississippi for January 1, 1915. The yearly change is given. These charts will give a value close enough for preliminary investigation purposes. For meridian determination for location surveys, see Chapter XI. "Polaris" and "Solar Meridians."

Explanation of Plates 37 and 38 (Taken from U. S. Coast and Geodetic Chart)

The solid lines on these charts are lines of equal magnetic declination.

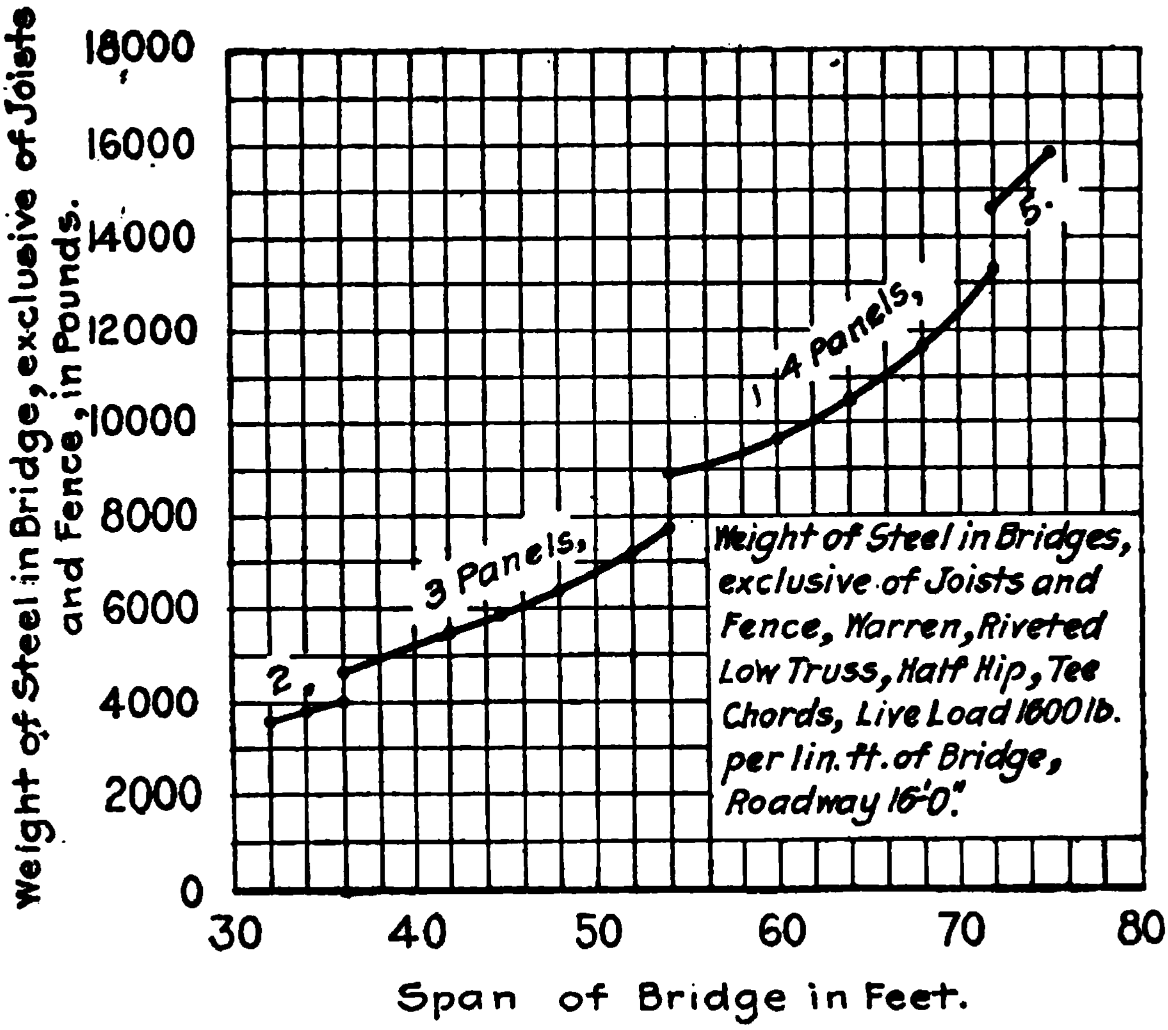
The dot and dash lines are lines of equal yearly rate of change in the magnetic declination.

The charts show the magnetic declination for Jan. 1, 1915.

Lines marked East Declination mean that the north end of the magnetic needle points east of true north.

Lines marked West Declination mean that the north end of the needle points west of true north.

For localities east of the line of no annual change the north end of the magnetic needle is moving west. For localities west of this line it is moving east at the rate shown by the lines of annual change. The location of the line of no annual change is shown on Plates 38 and 37G.


Weight of Steel in Bridge, exclusive of Joists and Fence, in Pounds.
18000
16000
14000
12000
10000
8000
6000
4000
2000
0
30
40
50
60
70
80
Span of Bridge in Feet.
2,
3 Panels,
4 Panels,
5.
Weight of Steel in Bridges, exclusive of Joists and Fence, Warren, Riveted Low Truss, Half Hip, Tee Chords, Live Load 1600 lb. per lin. ft. of Bridge, Roadway 16'0".

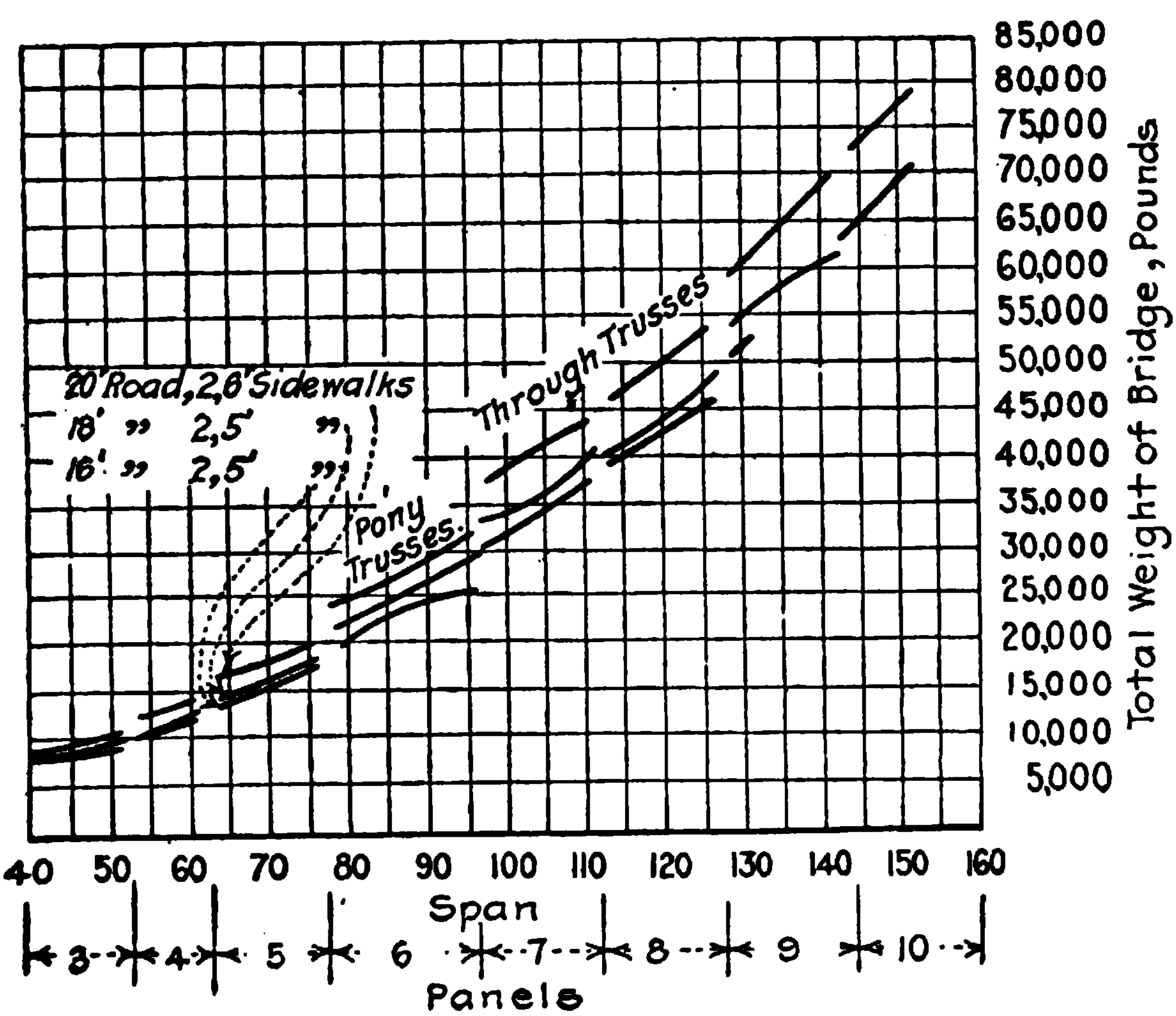

85,000
80,000
75,000
70,000
65,000
60,000
55,000
50,000
45,000
40,000
35,000
30,000
25,000
20,000
15,000
10,000
5,000
Total Weight of Bridge, Pounds
20' Road, 2,6' Sidewalks
18' " 2,5' "
16' " 2,5' "
Through Trusses
Pony Trusses.
40
50
60
70
80
90
100
110
120
130
140
150
160
Span
3
4
5
6
7
8
9
10
Panels

PLATE 37A.

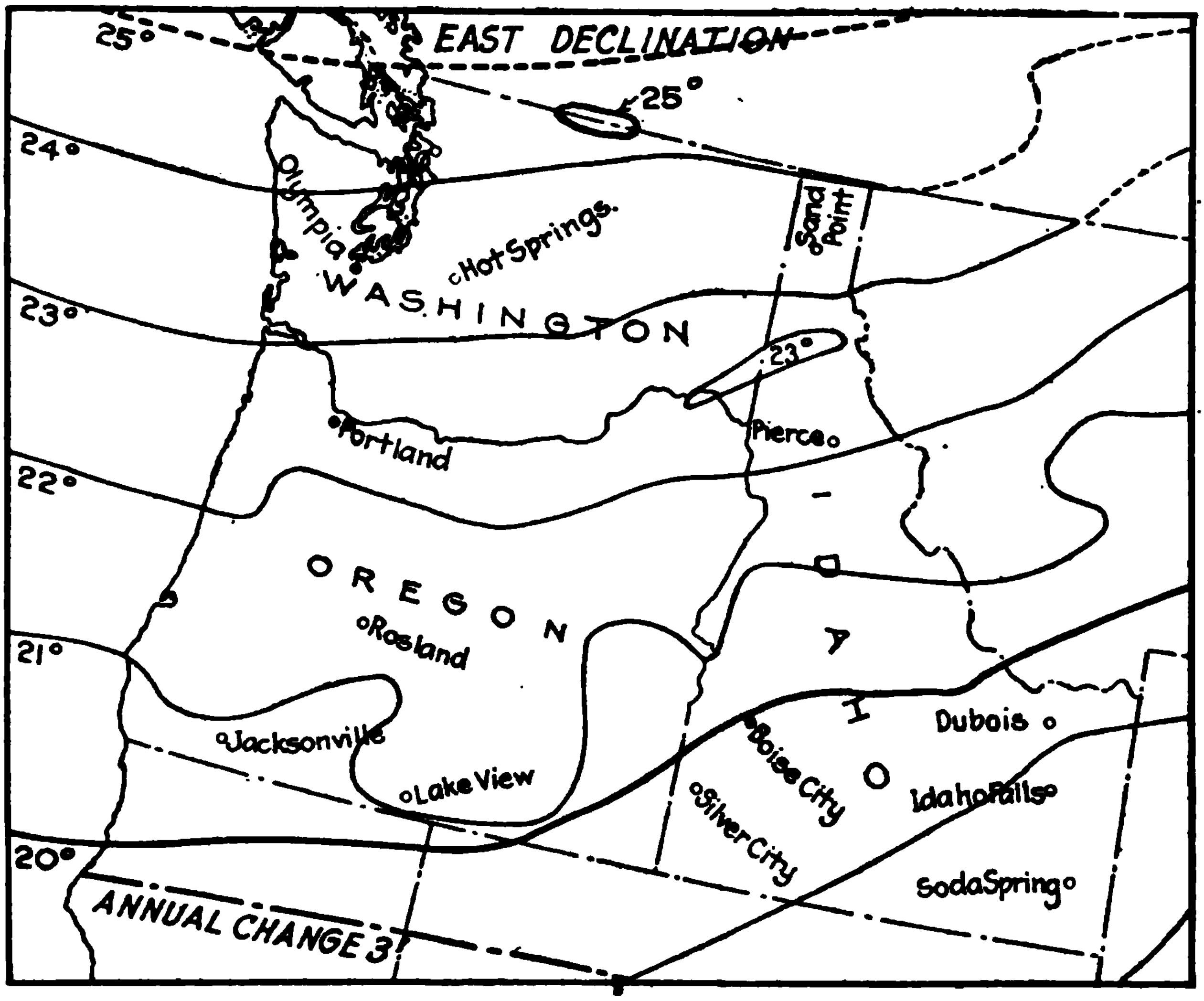
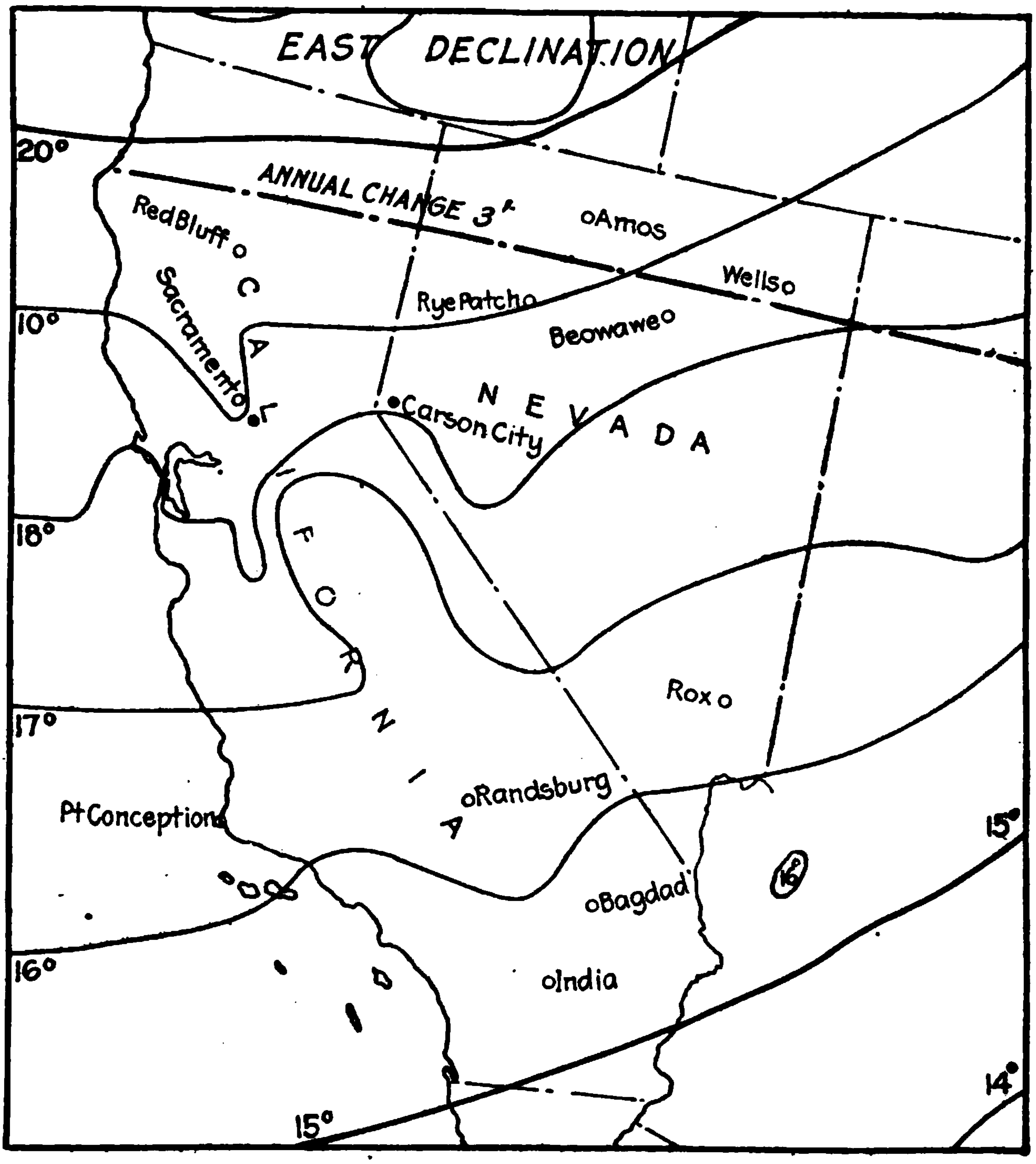
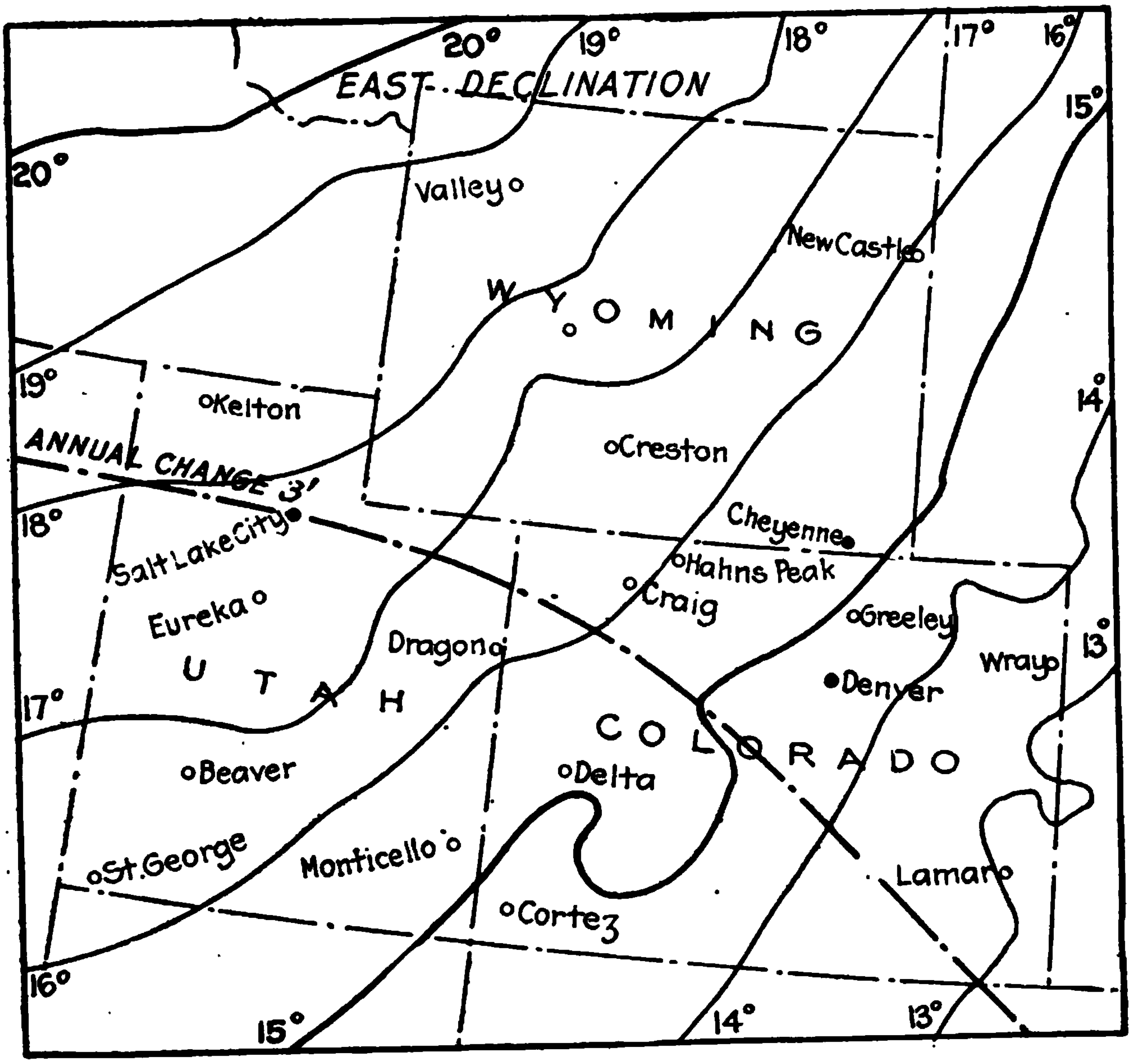
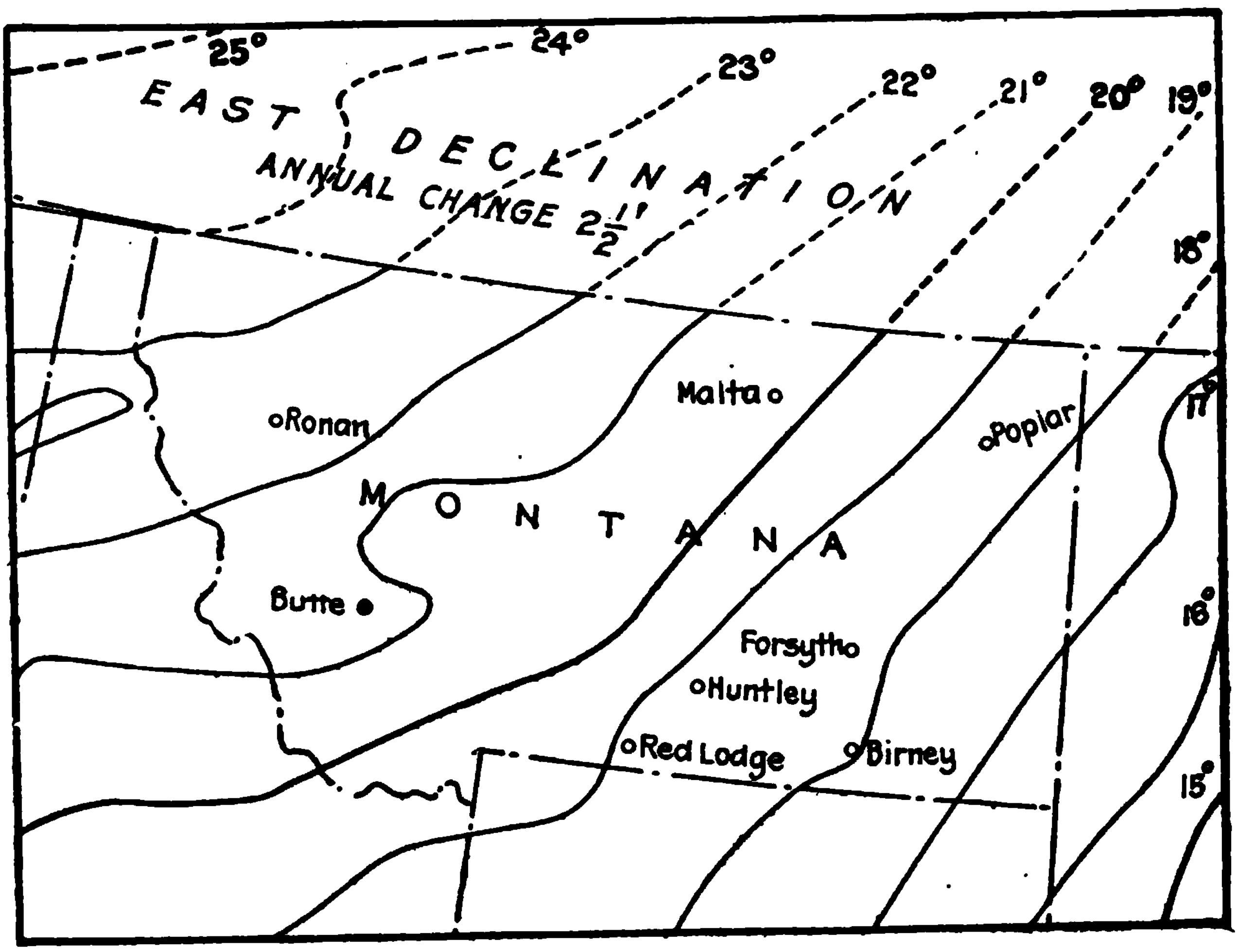

25°
EAST DECLINATION
25°
24°
Olympia
Hot Springs.
WASHINGTON
Sand Point
23°
23°
Portland
Pierce
22°
OREGON
Rosland
IDAHO
21°
Jacksonville
Lake View
Dubois
Boise City
Silver City
Idaho Falls
20°
Soda Spring
ANNUAL CHANGE 3'

PLATE 37B.

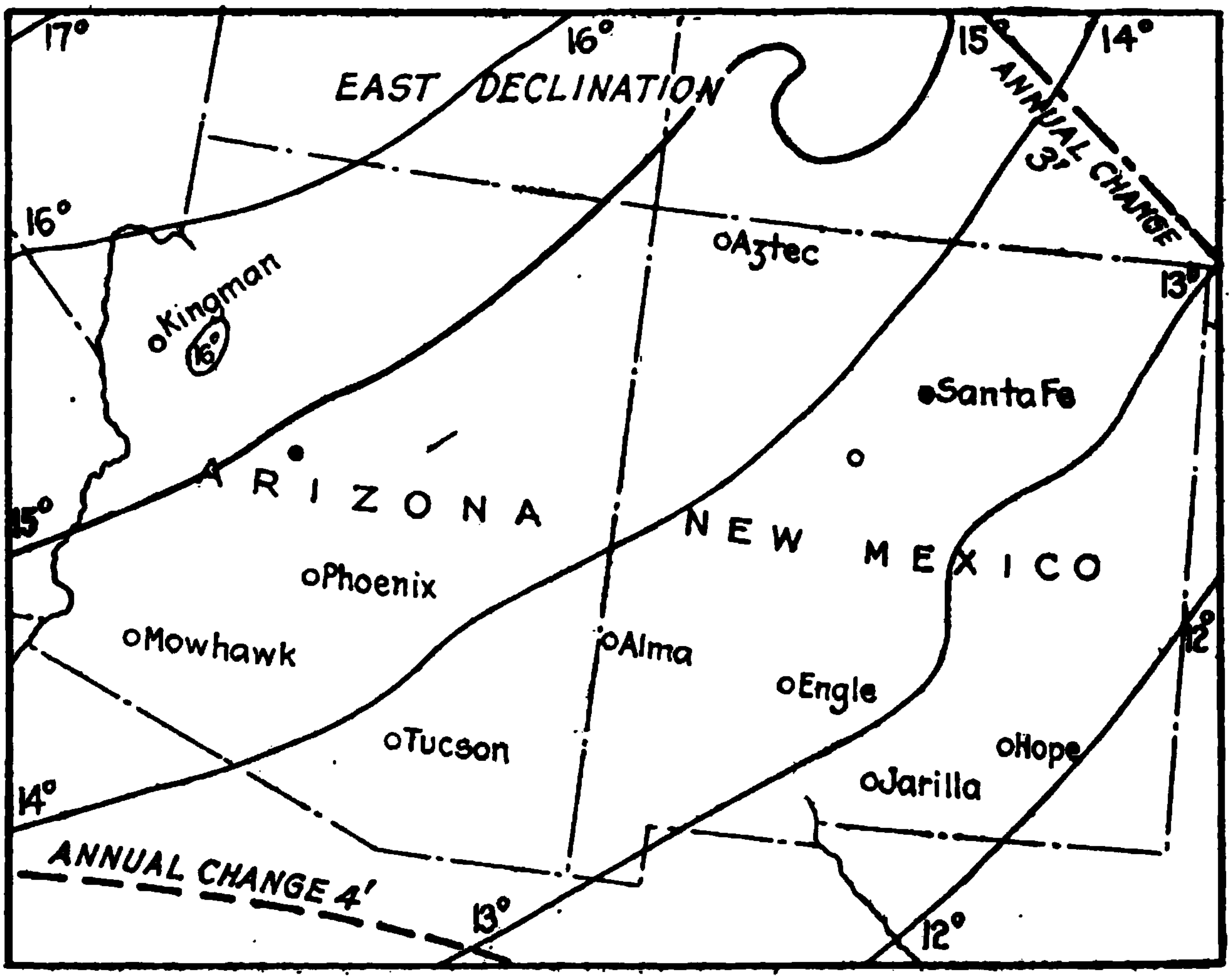

EAST DECLINATION
20°
ANNUAL CHANGE 3'
Red Bluff
Sacramento
Amos
Wells
Rye Patch
Beowawe
10°
CALIFORNIA
NEVADA
Carson City
18°
Rox
17°
Randsburg
Pt Conception
15°
Bagdad
16
16°
India
14°
15°

PLATES 37C AND D.





PLATES 37E AND F.



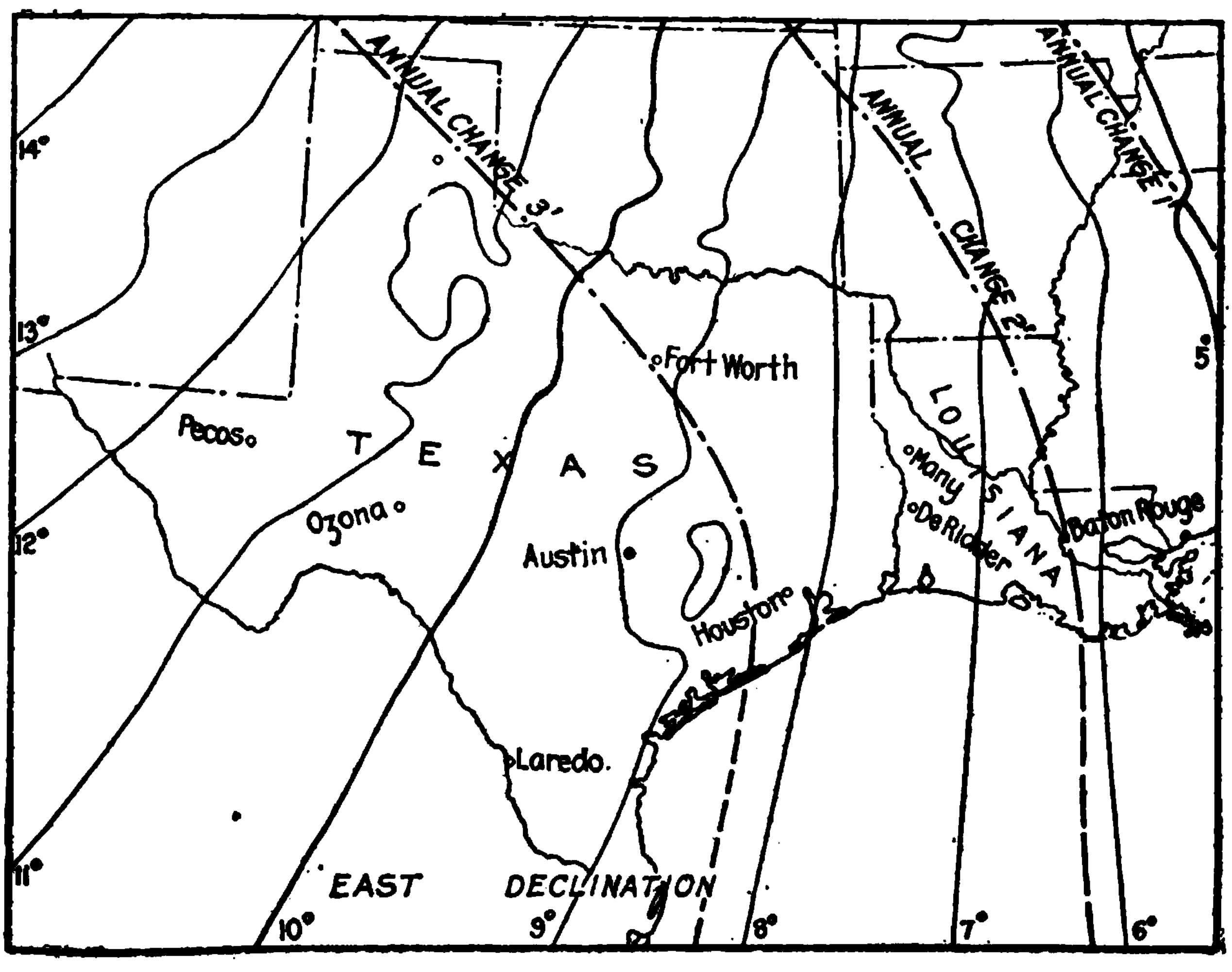


PLATE 37G.

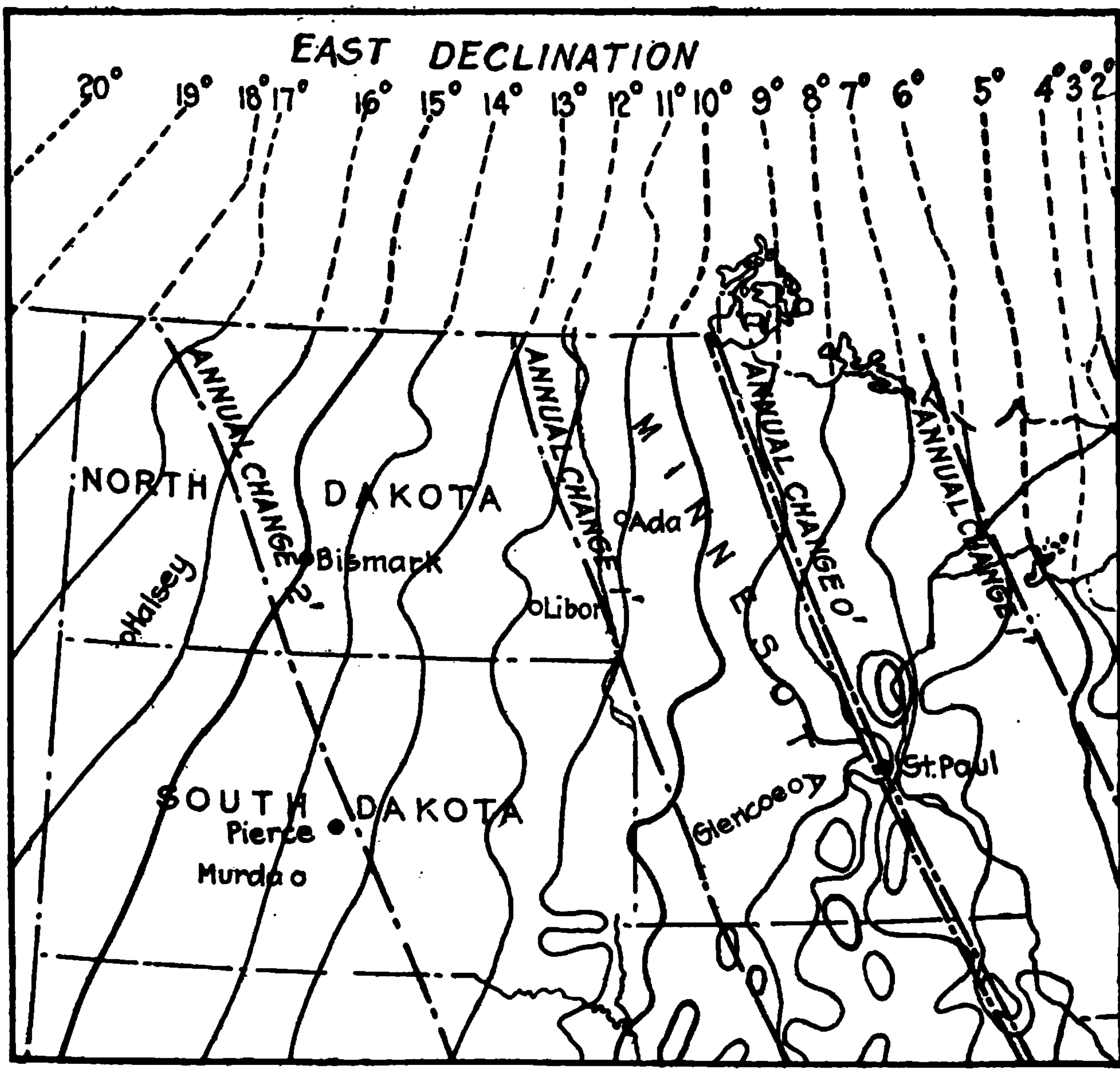


PLATE 37H.

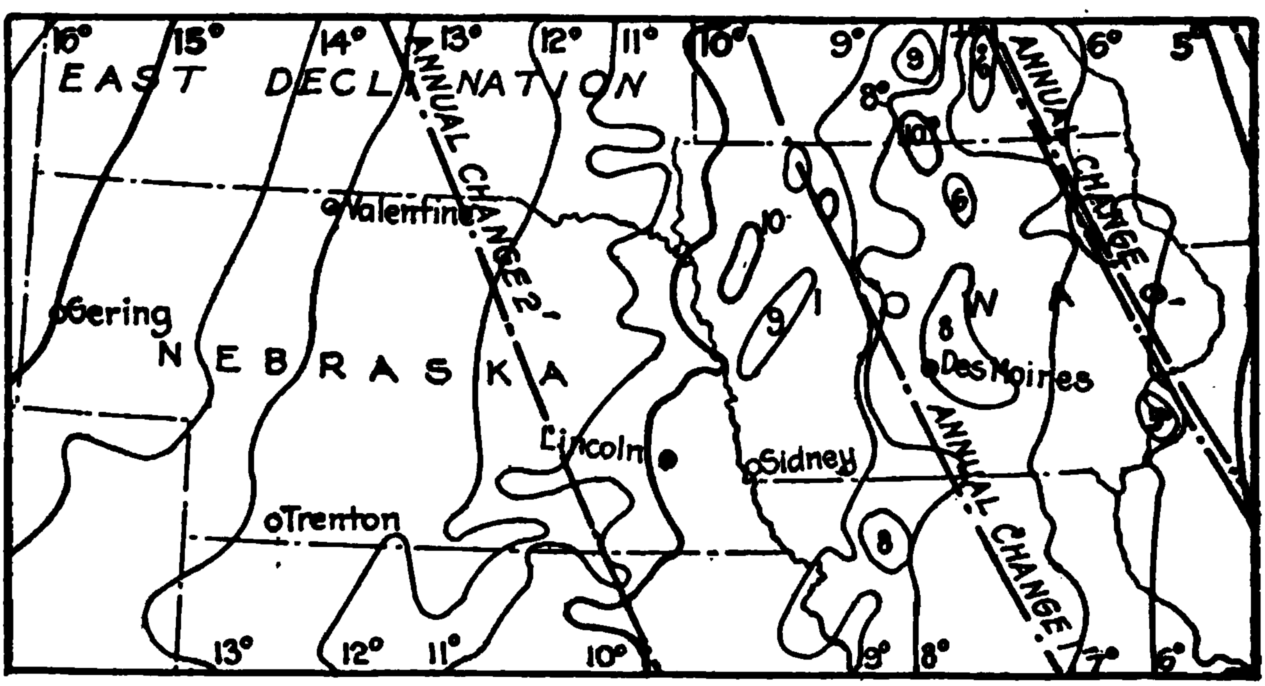


PLATE 37I.

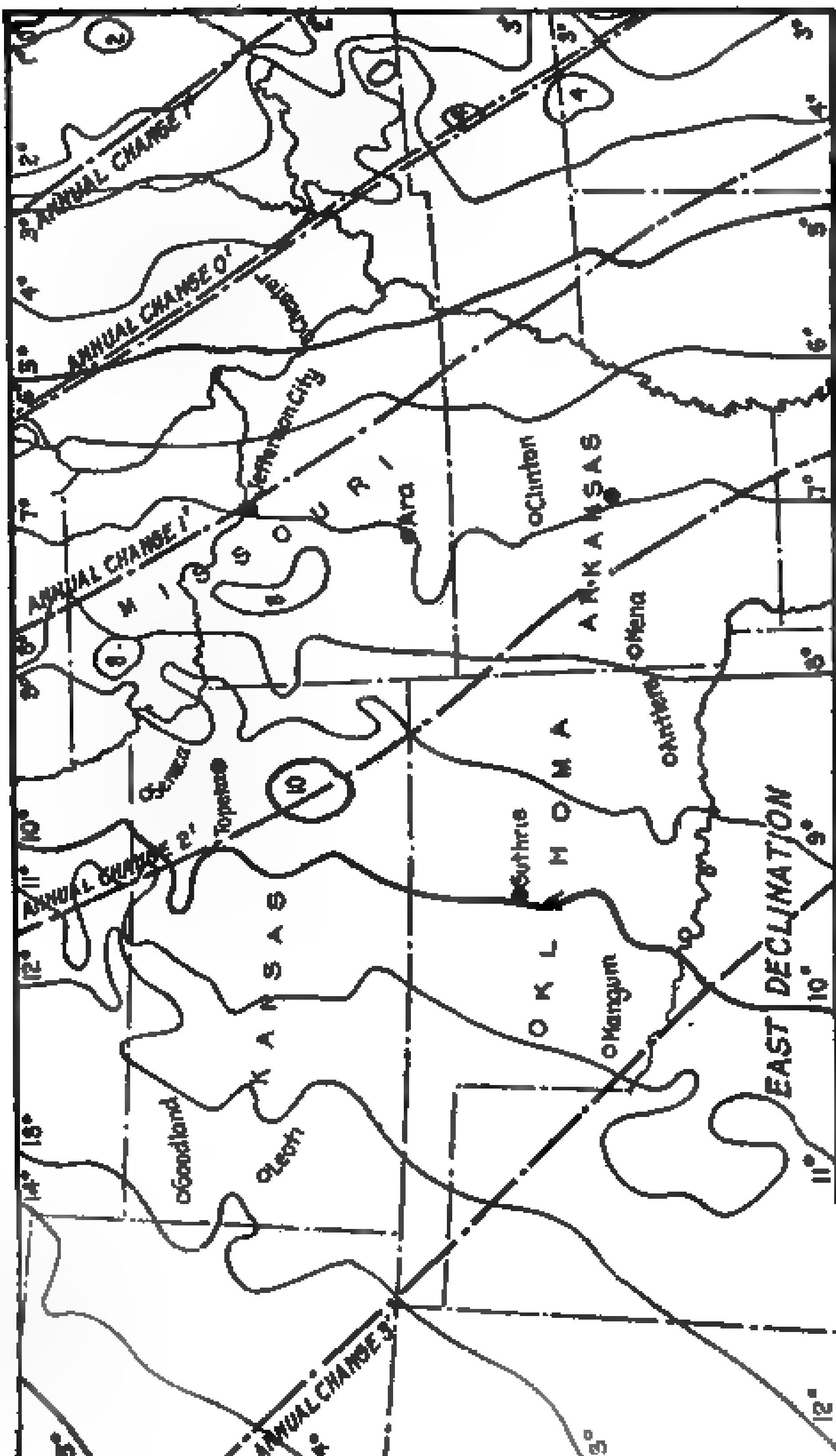
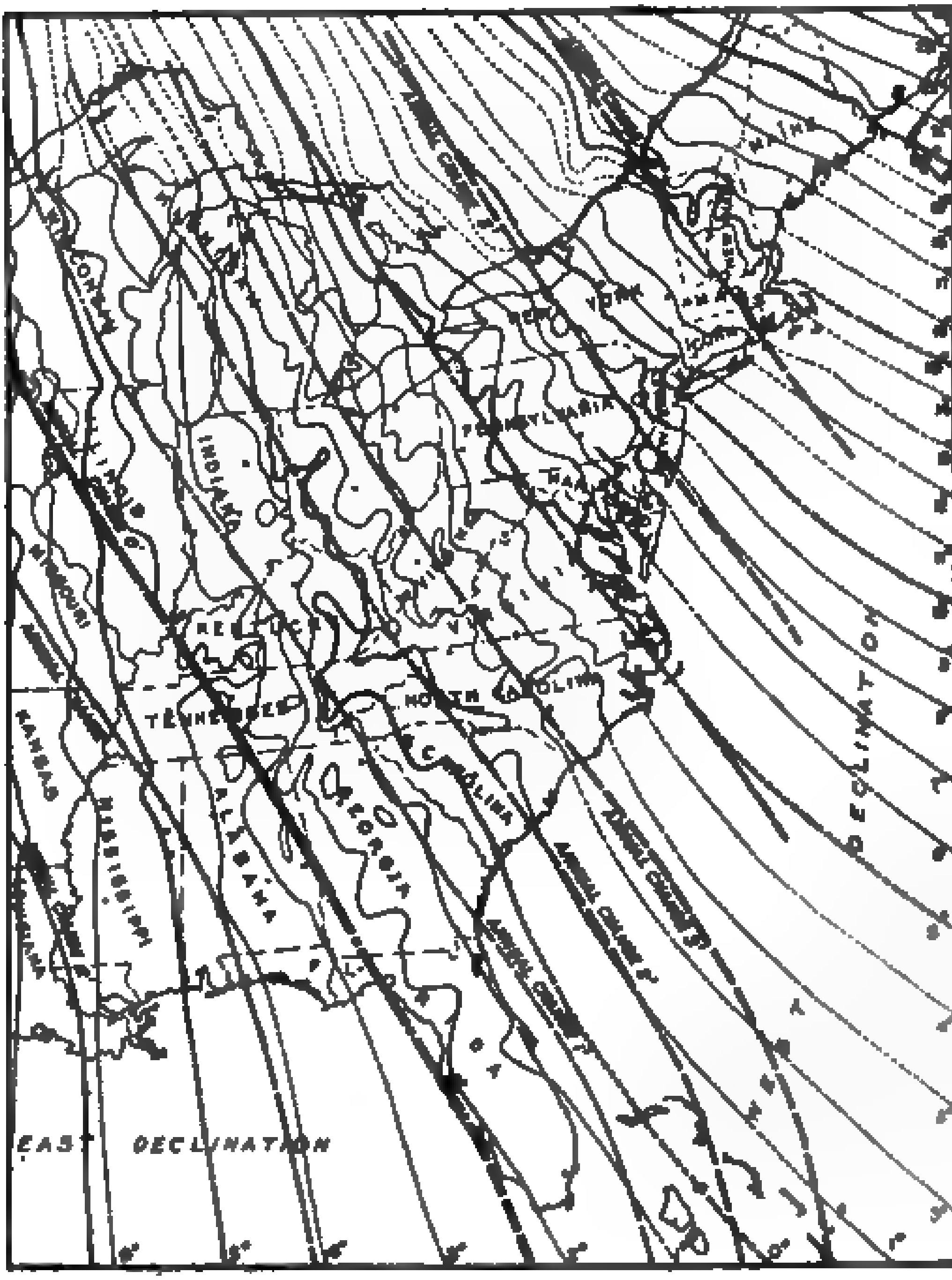

ANNUAL CHANGE 1'
ANNUAL CHANGE 0'
ANNUAL CHANGE 1'
ANNUAL CHANGE 2'
ANNUAL CHANGE 3'
EAST DECLINATION
M I S S O U R I
K A N S A S
O K L A H O M A
A R K A N S A S
Jefferson City
Topeka
Seneca
Ava
Clinton
Mena
Antlers
Guthrie
Mangum
Goodland
Leoti
2°
3°
4°
5°
6°
7°
8°
9°
10°
11°
12°
13°
14°
15°

PLATE 38.


NEW YORK
PENNSYLVANIA
INDIANA
MISSOURI
KANSAS
TENNESSEE
NORTH CAROLINA
ALABAMA
GEORGIA
MISSISSIPPI
EAST DECLINATION
DECLINATION

The following sample report shows a form in ordinary use for Preliminary Investigations which covers the information required.

REPORT ON PRELIMINARY INVESTIGATION OF THE RED GAP-BIG BEAR RANCH HIGHWAY IN PATERSON AND GRANT COUNTIES, STATE OF ————, 1919

State Commissioner of Highways,
Dear Sir:

Complying with your request of May 10th, a preliminary investigation of the proposed Red Gap-Big Bear Ranch Highway was made June 1st to June 10th.

There is only one feasible route via Clear River Ranch, Coal Basin, Stray horse Divide, See Creek and Blackwater river a total distance of 30 miles. This route is free from snow seven months in the year. A double track road from Red Gap to Coal Basin and a single track road with turnouts and permanent drainage structures for the remaining distance will cost approximately $175,000.

In case the entire project can not be undertaken by one appropriation, I recommend the following order of construction of the various sections shown on the accompanying map (page 317).

First in importance..................G 4, G 5,
Second " " ....G 7,
Third " " ....G 6,
Fourth " " ....G 2, G 3,
Fifth " " ....G 1, P 1, P 2,
Sixth " " ....P 3, P 4,
Seventh " " ....P 5,

The report in detail follows.

Signed,
Field Engineer.

TABLE OF CONTENTS

The field notes on which this report is based can be found in Field Book No. 153 Preliminary Investigation file.

1. Introduction

It is proposed to build a new road over Stray Horse Divide connecting the valleys of the Clear and Blackwater Rivers and to improve the location, grade and width of the existing roads in these valleys. The highway will extend from Red Gap in Paterson County to Big Bear Ranch in Grant County a distance of approximately 30 miles. It will open up a valuable farming section on the upper Blackwater River and will afford more direct communication between these two counties.

2. Length in Counties and Benefits

Paterson County.—Red Gap to Stray Horse Divide 8 miles.

Grant County.—Big Bear Ranch to Stray Horse Divide 22 miles.

Paterson County will be benefited by a better and quicker connection with communities to the south and by the large amount of tourist travel which will undoubtedly use this road.

Grant County will gain a more direct route to an isolated portion of its territory and will help the development of a promising farming section on the upper Blackwater River.

While none of this road lies in Socorro County, this county will be more directly benefited than Paterson County as the natural outlet for trade and produce up the Blackwater lies toward Lochiel.

3. Methods of Investigation

Field Work.—The entire line was covered twice on foot June 1st to 10th, noting the controlling points (aneroid elevations) the general classification of materials, the sidehill slopes and reasonable ruling grades.

Office Work.—The office estimate is based on paced distances checked by Forest Service maps and maps of the Clear River Railroad.

The excavation per running foot on sidehill work is based on cross slopes taken with an Abney level at frequent intervals and is figured on the principle of balanced sidehill sections adding different percentages for inequalities in profile.

The classification of excavation is made roughly from notes on the general character of the formations.

The drainage is approximated for the smaller structures. The larger bridges are noted in more detail.

Estimates have been prepared for various widths of roadway.

4. Present Condition of Roads and Trails

Paterson County (Red Gap to Stray Horse Divide).—There is a fair wagon road from Red Gap to Clear River Ranch about 2 miles south; a solid but poor wagon road from this point to Coal Basin; a fair road from Coal Basin to Stray Horse Station and a well

marked but steep trail from this point to the top of Stray Horse Divide.

Grant County (Stray Horse Divide to Big Bear Ranch).—There is an easy trail from Stray Horse Divide to Blackwater River approximately 8 miles; a very poor wagon road down Blackwater River from See Creek to Adams Ranch approximately 9 miles. The road between these points crosses the river eight or ten times by fords and can not be used at all if the water is much above low stage. Under the best conditions a good team can not haul over 1 ton.

From Adams Ranch to Big Bear Ranch (about 5 miles) the road is poor and dangerous in many places. It is so steep that one and a half tons is about the maximum load for an exceptionally good team under the best conditions.

While this project ends at Big Bear Ranch it should be noted that if the road from this point to Lochiel in Socorro County, the nearest railroad point, is not improved the value of this project will be practically lost. The present road to Lochiel is dangerous, limits a team load to about 1½ tons and will be an expensive road to improve. I estimate roughly that $40,000 will be required to put it into reasonably good shape.

5. General Topography

Paterson County (Red Gap to Stray Horse Divide) (See photographs No. 1 to No. 10).—From Red Gap south for about 2½ miles the topography is abrupt. Red sandstone and conglomerate cliffs and dykes hold the road location closely to the Clear River. From this point to about one-half mile south of Coal Basin occasional cliffs occur but a careful location will avoid them and it will be possible to gain some elevation along the sides of the valley. From the point to Stray Horse Divide and for a couple of miles south of the pass there are no cliffs and while the slopes are steep averaging 25° to 40° the location can be placed at any desired elevation. This strip of country is fortunately favorable to location.

Grant County (See photos No. 11 to 30).—From Stray Horse divide to Thompson's Ranch the formation is favorable for location on any desired grade. Few rock outcrops occur. The slopes average 20° to 25°.

From Thompson's Ranch down See Creek is an ideal road location. No solid rock, very little loose rock, easy water grade. The side slopes average 10° for one-half the distance and 20° for the balance of the way.

From the junction of See Creek and Blackwater River down the east side of the Valley to Buck Creek the location is easy on a sidehill averaging 25° side slope. There are no rock outcrops and very little loose rock. An easy grade can be obtained.

From Buck Creek to Spring Creek along the sidehill on the east side of Blackwater River the following conditions prevail. Average sidehill slope 30°; one-half mile of rock ledge slope of face approx. 60°. Expensive work can not well be avoided but an easy grade can be obtained.

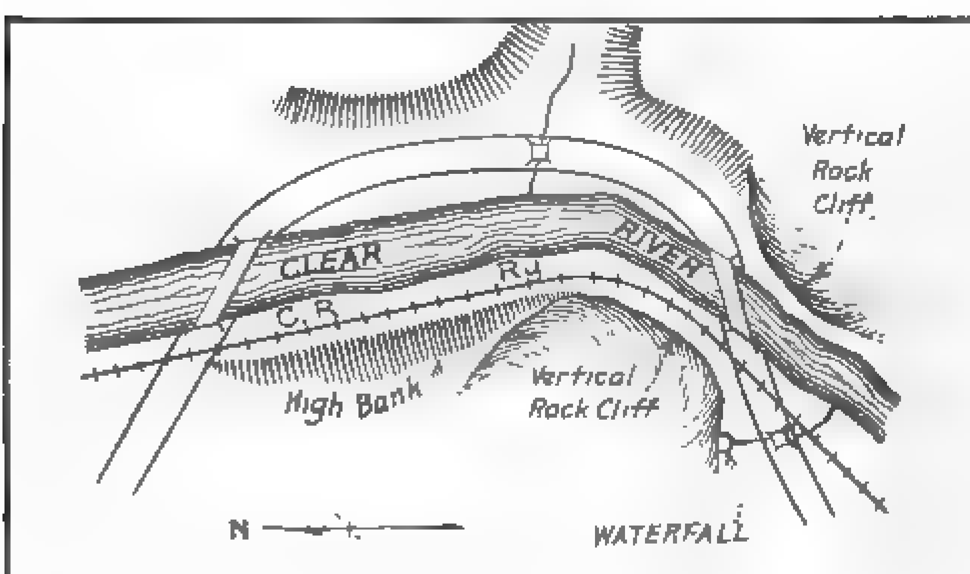
From Spring Creek to Adams' Ranch the formation on the east side of the valley is favorable for location at some distance away from the River. A ruling grade of 5% can be obtained at the worse places and ordinarily the grade is light. Benches and sidehill slopes are easy averaging 15° for ½ the distance and 30° for the remainder.

From Adams' Ranch to Big Bear Ranch the best location lies on the west side of the valley. Difficult country is encountered, heavy scrub oak brush, many large boulders and considerable solid rock. The River changes its channel frequently and any permanent road location must be placed beyond its reach necessitating expensive work.

The natural soil from Big Bear Ranch to Adams' Ranch is very slippery when wet. To get a good safe road Creek Gravel should be used as surfacing. Unless the roadbed is sloped toward the hill (one way crown) any of this location will be dangerous in wet weather. This same condition applies in a less marked degree all the way up Blackwater River to See Creek.

6. Proposed General Route

Paterson County.—From Red Gap, the proposed road follows the present road with some modifications to avoid unnecessary



rise and fall to the first crossing of the Clear River about 1¾ miles south of Red Gap. From this point to the mouth of the Canyon about ¼ mile the location is open to argument. The existing road crossed the river twice (see sketch above). Both of these bridges were wrecked by the flood of 1918 and temporarily the travel is using the railroad track between these points.

With the permission of the railroad, it would be possible to widen out the cut on the west side of the track and tunnel or half tunnel

for about 500 feet around the rock bluff point, eliminating the two bridges and two railroad crossings. On the other hand the road would be very close to the track for 1/4 mile and would in my opinion be more dangerous for horse traffic than the old location requiring two bridges. The bridge location is recommended.

From the mouth of the gorge the road will follow approximately the location of the present highway to the top of canyon hill and thence on a new location along the west side of the Clear River Valley to Stray Horse Divide.

Grant County.—Beginning at the County line at Stray Horse divide a new location will follow down the north side of See Creek to a point about 2 1/2 miles southwest of Thompson's Ranch and thence along the south and east side of See Creek and Blackwater River to Adams' Ranch. At Adams' Ranch the road will cross to the west side of the valley and remains on this side to Big Bear Ranch the end of the proposed improvement varying somewhat from the location of the present road to better short sharp grades and to avoid Creek flood areas.

7. Controlling Points (Aneroid Elevations)

Paterson County.	
Stray Horse Divide	9200
Bench between Cliffs at Coal Basin	8200
Top of Canyon Hill	8100
Bottom of Canyon Hill	7930
Red Gap	7800
Grant County.	
Stray Horse Divide	9200
Thompson's Ranch	7900
2 1/2 miles S. W. of Thompson's (See Creek Crossing.)	7500
Bench between Cliffs between Buck and Spring Creek	7150
Adams Ranch	6780
Big Bear Ranch	6600

8. Description of Location Problems Between Controlling Points

Paterson County

Stray Horse Divide to Coal Basin.—The difference in elevation of these two points is approximately 1000 feet. The direct distance is about 1 1/2 miles. In order to get a good grade and come somewhere near Coal Basin, which is probably desirable, it will be necessary to run south from Stray Horse Divide and then turn north. In this way any required ruling grade can be obtained and the length of road will depend entirely on the grade selected. The switchback can be made without too great cost by a careful location. I recommend a 5% grade with a length of 4 miles. The road in general will follow the contours. Two pronounced gulleys are

crossed which can be bridged or filled as determined on the location survey.

By the use of a 6% to 7% grade it is possible to run direct from Stray Horse Divide to the top of Canyon Hill. This solution should be carefully investigated but does not appeal to me to be as good as the 5% location as the topography is not as favorable for location and while it is shorter the lighter grade is to be preferred and the extra length of road south of the divide will be utilized in the future as a part of the road to Stone Quarry.

Coal Basin to Top of Canyon Hill.—Approximate length 1¾ miles. Along contour of steep sidehill for approx. ¾ mile and then along bench cut up by small swales and knolls. No special features. Grade any convenient to fit topography. No grade problem on this section. Excavation largely earth and loose rock. One 20′ span bridge required.

Top of Canyon Hill to Bottom of Canyon Hill at Mouth of Gorge.—Approximate length 0.6 mile. Along side of Canyon following present highway closely. Largely a question of equalizing grade by cut and fill. From Aneroid elevations and Abney level, I judge that a 6% grade can be obtained. Certainly a 7% can be built. This section of the road will be expensive and will govern the ruling grade from Red Gap to Stray Horse Divide. The excavation will be approximately 50% solid rock. One 20′ span bridge will will be required.

Mouth of Gorge (at Bottom of Hill) to Red Gap.—Approximate length 2 miles. From mouth of gorge ¼ mile south to wagon road on the west side of the river the location is the most expensive of the entire project. This strip will require either two bridges or heavy rock work as previously discussed. The bridges are recommended. From this point to Red Gap there are no difficult problems as the road will follow in general the present location and can be cheaply built. Another bridge at Red Gap will better the location and increase the convenience of the road.

Grant County

Stray Horse Divide to Thompson's Ranch.—The difference in elevation is approximately 1300 feet. It is desirable to get down to a natural bench at Thompson's ranch. The length of road between these points will depend on the ruling grade selected. As it is a long climb I recommend 5% with a length of 5 miles which can be obtained with one switchback turn. The country is favorable for location. Excavation is largely earth and some loose rock.

Thompson's Ranch to See Creek Crossing.—Approximate length 2¼ miles. Ideal road location on bench. Easy grade. Excavation practically all earth. Plow and machine scrapper work. No grade problem. One 20′ span bridge required.

See Creek Crossing to Buck Creek.—Easy sidehill location except for ½ mile of rock ledge near Buck Creek. The location should keep upon the sidehill to avoid abrupt river banks and slides due to freshet scour.

Buck Creek to Adams' Ranch.—Easy sidehill and bench location. No difficulty in obtaining grades less than the maximum. Excavation earth and loose rock.

Adams' Ranch to Big Bear Ranch.—Location problem one of protecting road from River floods, also avoiding ledge and large boulder rock work. No hard grade problem. Excavation 50% loose rock, boulders and solid ledge.

9. General Recommendations and Costs

The cost of construction under present conditions is uncertain. The prices used in the following detail estimates should be carefully noted in considering the possibility of cheapening the work by the use of convict labor. The costs used are for contract work and may vary greatly in a short time.

I recommend for this project a double track sidehill section (S–14′) from Big Bear Ranch to Coal Creek; a single track sidehill section (S–10) with turnouts from Coal Creek up to Blackwater River, See Creek over the Divide and down to the top of Canyon hill in Paterson County. A double track road from this point to Red Gap. Permanent culverts and bridges. Ruling grades of short 7% and long 5%. Alignment limited as a rule to a minimum curvature of 100′ radius with a few 40′ radii at exceptionally bad places.

The cost of this type of road is estimated at approximately $175,000 divided as follows:

Clearing and excavation	$108,000
Permanent culverts	20,000
Permanent bridges over 10′ span	35,000
Engineering	12,000
Total	$175,000

If it is not possible to construct the entire project by one appropriation it would be well worth while to build from Big Bear Ranch to See Creek at once to open up the new farming section on the Upper Blackwater. The cost of this portion of the road would be about $70,000.

For details and various combinations of design see the following estimates by sections.

10. Detail Estimates

Classification of Materials.—The classification of excavation can not be accurately made; it is based on the following assumptions.

Where the road is located on a bench near the bottom of a slope which appears to be slide or wash formation and no rock outcrops are visible the excavation is classed as 99% common and 1% rock.

Where the location is on a steep main mountain slope of 25° to 35° covered with loose rock but no solid rock outcrops are visible the assumption has been that solid rock will be encountered 6 feet back of the slope surface.

Where occasional outcrops occur rock is assumed 4 feet back of the surface.

Any extended rock ledge has been noted.

Unit Prices

Clearing	
Sage brush	$ 30 per mile
Light brush and trees	$ 30 " acre
Medium brush and trees	$100 " "
Excavation	
Solid rock	$1.00 to $1.50 per cu. yd.
Tunnel rock	4.00 " " "
Common Exc.	
Turnpike in earth	0.18 " " "
Sidehill plow and scrapper	0.30 to 0.40 " " "
Wagon haul and scrapper	0.40 " " "
Concrete	$12.00 " " "
18″ corrugated pipe	2.00 " foot
Rough rubber retaining wall	2.00 " cu. yd.

Division into Sections.—For the purpose of estimating the road is divided into the following sections.

Paterson County

Sec. P-1 Stray Horse Divide to Coal Basin	4.0 miles
Sec. P-2 Coal Basin to top of Canyon Hill	1.8 "
*Sec. P-3 Canyon Hill	0.6 "
*Sec. P-4 Canyon Hill to Clear River Ranch	0.25 "
*Sec. P-5 Clear River Ranch to Red Gap	1.75 "
Total Paterson Co.	8.40 "

Grant County

Sec. G-1 Stray Horse to Thompson's Ranch	5.0 miles
Sec. G-2 Thompson's Ranch to See Creek Crossing	2.5 "
Sec. G-3 See Creek Crossing to Blackwater River	1.0 "
*Sec. G-4 See Creek and Blackwater to Buck Creek	2.5 "
*Sec. G-5 Buck to Spring Creek	2.0 "
*Sec. G-6 Spring Creek to Adams' Ranch	4.5 "
*Sec. G-7 Adams' Ranch to Big Bear Ranch	4.3 "
Total	21.8 "

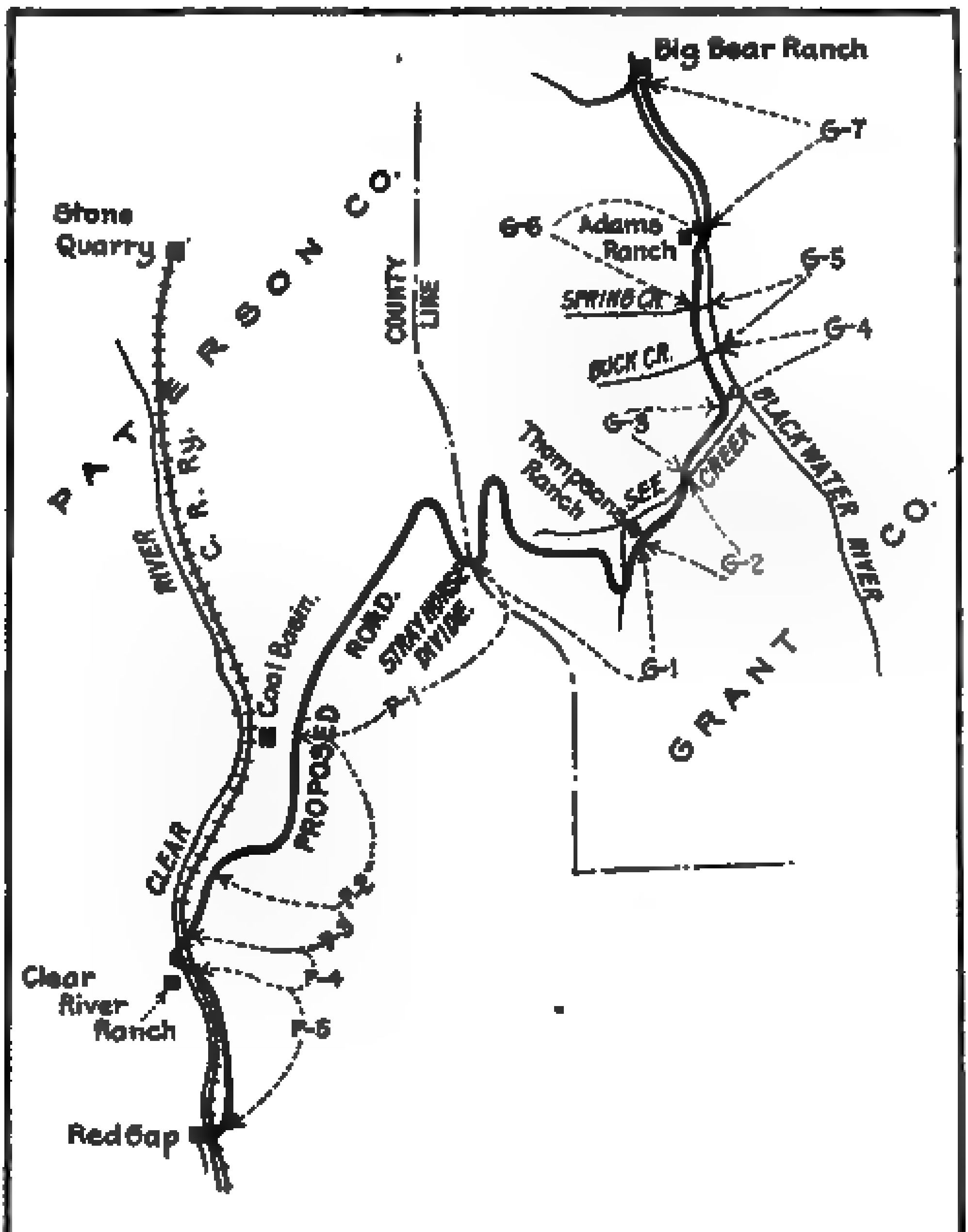
Note.—See map for location of these sections. The sections marked with a * have a poor wagon road at present which however can be used. Sections having no star require new construction to permit wagon traffic.

Estimate of Sections. Section P-1.—(Length 4.0 miles.)

Clearing.—Six acres per mile for 3 miles = 18 acres @ $100 = $1800.

Drainage.—Say 10 culverts per mile for 4 miles @ \$700 per mile = \$2800.

Excavation for Double Track Road.—Sidehill slope averages 27°. Excavation per mile for balanced section S = 14 equals approximately 13,000 cu. yd. for a 1 : 1 cut slope which is considered



safe for this material. Add 25% for inequalities of profile giving 16,200 cu. yd. per mile or 55,000 cu. yd. for 4 miles. It is estimated that 20% of this or 11,000 cu. yd. are rock excavation and the balance 44,000 cu. yd. are common.

44,000 cu. yd. common @ $0.40		$17,600
11,000 " " rock @ 1.20		13,200
Total excavation		$30,800

Excavation for Single Track Road S–10.

Exc. per mile balanced section	7,400 cu. yd.	
Add for profile 25%	1,850 " "	
	9,200 " "	
Assume 10% rock	900 " "	per mile
Assume common exc	8,300 " "	" "

Cost of Excavation for 4 miles.

3,600 cu. yd. rock	@ $1.50	$5,400
33,000 " " common	@ $0.33	11,000
Add for turnouts 5 to the mile		
500 cu. yd. rock @ $1.20		600
1,500 " " common @ $0.40		600
Total		$17,600

Summary of Cost Section P-1.

DOUBLE TRACK ROAD		SINGLE TRACK ROAD	
Clearing	$ 1,800	Clearing	$ 1,800
Drainage	2,800	Drainage	2,800
Excavation	30,800	Excavation	17,600
	$35,400		$22,200
Contingencies, wall, etc	2,600	Contingencies	1,800
	$38,000		$24,000
Equals $9500 per mile		Equals $6000 per mile	

Estimate Section P-2.—(Length 1.8 miles.)

0.8 miles similar to section P-1

1.0 miles average side slope 15°

Estimate of the easy mile (side slope 15°)

Clearing 6 acres @ $50			$300.00
Drainage (ordinary)			500.00
20′ span bridge			800.00
Excavation (see S-14)	3300 cu. yd. per mile		
Add for profile 25%	800 " " " "		
	4100 " " " "		
Rock excavation	100 " "	@ 1.50	$ 150.00
Common excavation	4,000 " "	" 0.30	1200.00
			$2950.00
Contingencies			150.00
Total			$3100.00

Summary P-2.

Double Track		Part Single and Part Double
0.8 miles similar to P-1		
@ $9500 per mile =	$7,600	
@ $6000 per mile =		$4800.00
1.0 miles as per estimate above....	3,100	3100.00
	$10,700	$7900.00
Say..............	11,000	Say... 8000.00

Estimate Section P-3.—(Length 0.6 miles.) Double track road based on hand level profile.

Clearing 3 acres @ $100..................	$ 300.00
3000 cu. yd. common @ $0.40..............	1200.00
3000 " " rock @ $1.25..................	3750.00
Ordinary drainage........................	500.00
1 20′ span bridge........................	800.00
	$6550.00
Contingencies........................	150.00
Total................................	$6700.00

Estimate Section P-4.—(Length 0.25 miles.)

Estimate No. 1.—Based on location requiring two bridges over the Clear River.

Clearing................................	$ 20.00
1000 cu. yd. common exc. @ $0.40..........	400.00
200 " " rock @ $1.50..................	300.00
400 " " rip-rap @ $1.00..............	400.00
2 (80′ span solid floor steel truss bridges)....	16,000.00
1 (20′ span concrete bridge)..............	800.00
	$17,920.00
Say..................................	18,000.00

Estimate No. 2.—Based on half tunnel west of track.

Clearing................................	$30.00
5000 cu. yd. of common exc. @ $0.40........	2,000.00
4500 " " rock tunnel work @ $4.00......	18,000.00
Stone wall between track and road..........	900.00
	$20,930.00
Say..................................	$21,000.00

Estimate Section P-5.—(Length 1.75 miles.) Double track road. Approximately same cost per mile as Section P-2 on the easy mile.

1.75 miles @ $3100 per mile..............	$ 5,425.00
Possible bridge at Rip Gap................	8,000.00
	$13,425.00
Say..................................	$14,000.00

Summary of Costs, Paterson County

Section	Double Track	Single Track Road with Turnouts
P-1	$38,000	$24,000
P-2	$11,000	8,000
[1] P-3	7,000	
[1] P-4	18,000	
[1] P-5	14,000	
	$88,000	
Engineering	4,000	
Total appropriation	$92,000	

Estimated total cost for double track road Sec. P-3, P-4 and P-5 and single track road to the divide Sec. P-1, and P-2 is $75,000.

Estimated cost of cheap single track road connecting present road to the divide Sec. P-1 and P-2, with temporary drainage structures and 6% ruling grade instead of 5% $25,000.

Cost Estimate, Grant County

In a similar manner detail estimates are made for the sections in Grant County as summarized below. These estimates can be found in computation file F-32. They are not included in this report as they are bulky.

Summary of Costs, Grant County

Section	Double Track (S–14)	Single Track (S–10) With Turnouts (S–14)
G-1	$ 32,000	$ 22,000
G-2	33,000	3,000
G-3	5,000	3,000
G-4	10,000	7,000
G-5	20,000	12,000
G-6	26,000	20,000
G-7	36,000	25,000
	$132,300	$ 92,000
Engineering....	7,700	8,000
Appropriation..	$140,000	$100,000

Total Summary of Recommended Construction

Paterson County	$ 75,000
Grant County	100,000
Total	$175,000

[1] Sections have usable wagon road at present.

RECONNAISSANCE SURVEYS

The methods described for ordinary investigations can be used for most cases but for heavily wooded country or extremely difficult and rough topography a more careful survey is desirable.

Methods.—For open barren country the transit stadia method is preferred by the author using magnetic bearings, stadia distance, vertical angle profile and cross slopes and ordinary note book sketches and recording. The map is plotted up on a scale 1000 ft. to the inch and the profile 100′ to the inch. The line is marked in the field by tall stakes or lathes with a strip of cloth attached.

Work of this kind can be done by two men with very simple equipment. In remote regions a third man to move and care for camp equipment is required (see Chapter XII).

Engineering Equipment

Light mountain transit with stadia and verticle circle.
Light stadia rod, 8′ to 10′ long.
Camera.
Note books, maps, etc.
100′ steel tape.
2 aneroid barometers.

For heavily wooded country the U. S. Geological methods are the cheapest and most satisfactory using a light 15″ sketch plane table and tripod oriented with a magnetic needle; 6″ gun sight alidade; 500′ linen tape coated with paraffin for distance. Aneroid intermediate elevations checked by flying lines of spirit levels or stadia levels along trails.

The main advantage of this method is that it requires no cutting as direction is obtained by sighting by ear to a yell or whistle. It also gives a complete contour map of all the territory that the road can possibly traverse and makes it possible to lay out a better final location than any amount of scouting where the engineer depends on his memory and sense of direction for his final location. The projected line is then followed with a rough plane table traverse, slopes, etc., taken and the estimate made.

Work of this kind can be done by two men with very simple equipment for a cost ranging from $10 to $30 per square mile mapped. A convenient scale to work on is 2000′ to the inch and a contour interval ranging from 10′ to 50′.

A third man to move and care for camp is desirable.

Engineering Equipment

15″ Plane table with tripod.
500′ Linen tape.
6″ Gun sight alidade in leather case.
100 Steel tape.
Plane table map paper.

2 Aneroid barometers
Light mountain transit with stadia (for flying levels).
Stadia rod.

Conclusion.—It should be borne in mind that if engineering is to be of value it must be thorough and that new locations will often fix roads for generations.

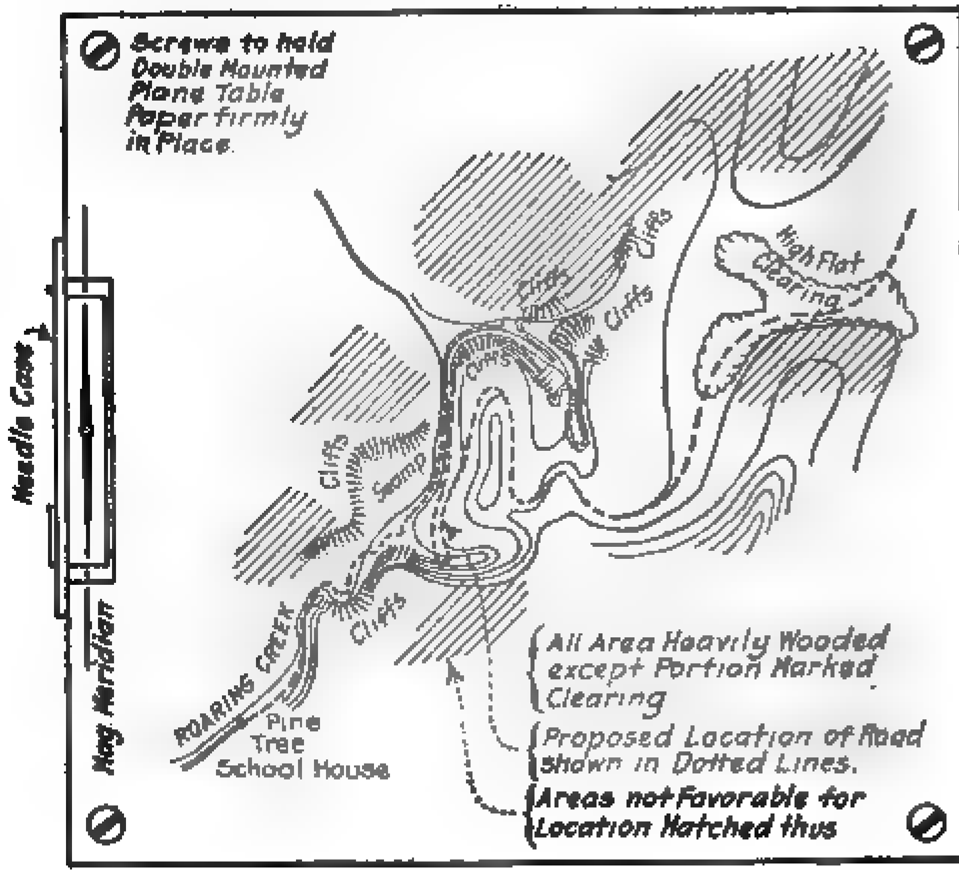


Fig. 61.—Sample plane table map.

There should be no hesitation in spending what ever is needed even if it seems all out of proportion to the cost of the actual construction work to be performed within a year or so. Government programs carry out this principle and they are often criticised for high engineering cost but it is well worth while looking to the future. The engineering program must be complete or it might just as well be discarded entirely.

CHAPTER XI

THE SURVEY

The chapter on survey will be handled under two main divisions:
(*a*) Improvement of existing roads.
(*b*) Location of new roads.

(*a*) FOR THE IMPROVEMENT OF EXISTING ROADS

As the survey furnishes the information for the design, it must be carefully made in regard to the essential features. These are alignment, levels and cross-sections, drainage, information concerning foundation soils, available stone supply, available sand, gravel, filler, etc.; direction and amount of traffic, railroad unloading points, the location of possible new sidings, and such topography along the road as will have a bearing on the design. The survey should be made not more than a year before construction starts and during the open season, as a snowfall of any depth makes the work unreliable and only fit for a rough estimate. When contracts based on winter surveys are awarded it is always necessary to take new cross-sections to insure a fair estimate of the excavation.

A party of five men is a well-balanced force for surveys of this character.

Force	*Equipment*	*Stationery*
Engineer	Transit	Reports
Instrument man	Level	Pencils
Three helpers	2 100′ steel tapes	Notebook
	3 50′ metallic tapes	U. S. G. S. map.
	3 pickets	
	2 level rods	*Stakes*
	Pocket compass	For preliminary survey
	Hatchet	110 stakes per mile
	Sledge	For construction
	Axe	220 stakes per mile
	Keel	

The Center Line.—The placing of the center-line hubs (transit points) requires good judgment and should be done by the chief of the party. In locating them he considers the principles of alignment discussed in Chapter I. The hubs are placed at tangent intersections and sometimes at the P. C.'s and P. T.'s of curves and are referenced to at least three permanent points that will not be disturbed during construction. (See sample page of notes, Fig. 62.)

The deflection angles at the tangent intersections are usually read to the nearest minute, taking a double angle to avoid mis-

takes; the magnetic bearing of each course is recorded. For all deflection angles over 4° it is good practice to figure and run in on the ground the desired curve. Curves with central angles of less than 4° can be run in with the eye during construction.

The center line is marked at intervals of either fifty or one hundred feet (see cross-section, page 325) in any convenient manner; the alignment of these points should be correct to within 0.2 and the distance along the line to within 0.1 per 100 feet of the length; any attempt to get more accurate stationing is a waste of time. The chaining may be done on the surface of the ground up to a grade of 5 % with no objectionable error; beyond that slope, however, the tape should be leveled and plumbed. Steel tapes should be used for chaining the center line and referencing the hubs

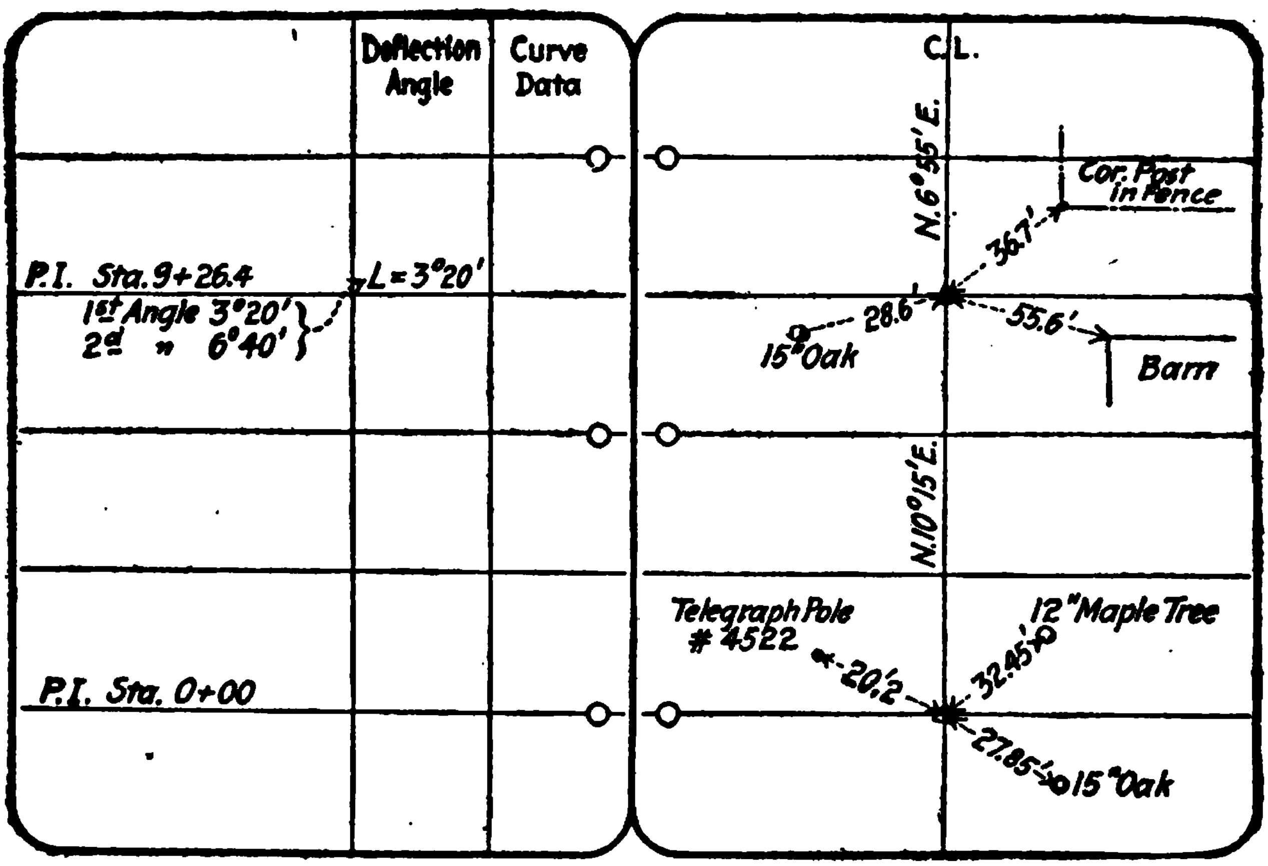


FIG. 62.—Alignment notes.

A convenient method of marking the actual center line stations is to use a nail and piece of flannel; red flannel for the 100′ stations and white flannel for the intermediate 50′ stations, if needed. Where the soil is sandy, or muddy, and these nails would be kicked out or covered, a line of stakes can be set outside of the traveled way on a specific offset from the center line. However, if an offset line is used the chaining of all curves should be done on the center line to insure a correct center line distance and the stakes placed radially on the desired offset. Railroad spikes make good permanent transit points and are easily placed.

At the same time that the line is run it is just as well to paint the 100′ station numbers on any convenient place where they can be readily seen, as stations marked in this manner make it much easier to sketch in the topography than if marked in chalk on stakes. Also, if the stations are permanently marked it is

easier for the construction engineer to pick up the transit points at some future time.

A party of five men will run from two to four miles of center line a day, the speed depending upon the number of curves and length of tangents, if the hubs have been previously placed and referenced. If the hubs are placed at the same time the line is run, the work is greatly delayed.

Two men can place and reference the transit points at the tangent intersections at the rate of from four to ten miles per day.

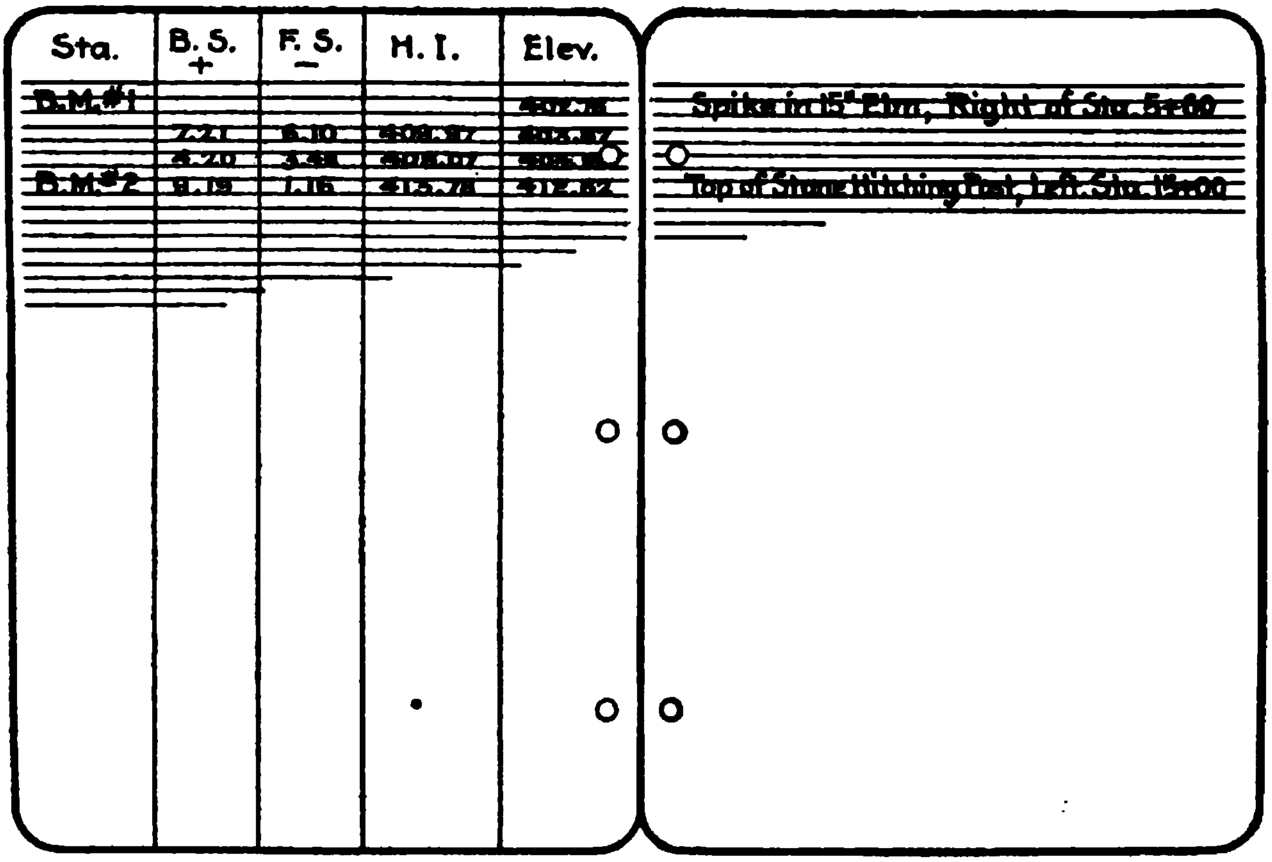


FIG. 63.—Bench level notes.

Levels and Cross-Sections.—Bench levels are run in the usual manner; the levels will be sufficiently accurate if the rod is read to the nearest 0.01′; for such work any good level and a self-reading rod graduated to hundredths are satisfactory. Benches are established at intervals of 1000–1500 feet; they must be substantial, well marked, and so situated as not to be disturbed during construction. A small railroad spike in the root of a tree, a large boulder, or the water table of a building make good benches.

The bench levels may be referred to some local datum in general use or to the U. S. levels, or the datum can be assumed. In running bench levels it is better to use each bench as a turning point, as side-shot benches may be wrong even if the line of levels is correct.

Cross-sections are taken at either 100′ or 50′ intervals, at all culverts, possible new culvert sites, and any intermediate breaks not shown by the normal interval. Enough sections are taken to show the constantly changing shape of the road.

The distance of the shots from the center line of the road is read to the nearest 1.0′ where the ground has no abrupt change of slope

and to the nearest 0.5′ where there is a well-defined abrupt change. The elevations are read to the nearest 0.1′. The sections should extend from fence line to fence line, or in villages from sidewalk to sidewalk, and the position of the pole lines, tree lines, curbs, etc., noted. Engineers differ as to whether the sections should be taken at a normal interval of 50′ or 100′.

Table 29 gives the difference in the computed quantity of earthwork using 50′ and 100′ sections with intermediate sections at well-defined breaks in the grade.

TABLE 29

Name of Road	Length Figured	Character of Road	Excavation 50′ Section	Excavation 100′ Section	Approximate Difference	Per cent of Difference
			Cu. Ft.	Cu. Ft.	Cu. Ft.	
Scottsville Mumford ...	1 mile	flat	61,444	61,995	550	+ 9/10 %
Scottsville Mumford ...	1 "	hilly	111,109	111,700	600	+ ½ %
Leroy Caledonia	1 "	rolling	57,840	60,560	2700	+ 4¾ %
*Leroy Caledonia	¾ "	flat	77,841	78,659	800	+ 1 %
Clarence Center	1 "	rolling	73,727	73,048	700	− 1 %
Clarence Center	1 "	flat	38,037	39,415	1400	+ 3 7/10 %
Lockport Tonawanda ...	1 "	flat	59,096	59,470	400	+ 7/10 %
*East Henrietta Rochester	1 "	rolling	37,275	36,075	1200	− 3¼ %

The following tabulation shows the variation for shorter sections of the starred roads.

Name of road and Station to Station	Quantities by 50′ Sections	Quantities by 100′ Sections	Approximate Difference	Per cent of Difference
	Cu. Ft.	Cu. Ft.	Cu. Ft.	
Leroy				
Caledonia, 80– 90 ...	19,151	19,525	400	+ 2 %
" 90–100 ...	21,915	23,415	1500	+ 7 %
" 100–110 ...	21,555	20,689	900	− 4 %
" 110–120 ...	15,220	15,030	200	− 1 3/10 %
Total and averages .	77,841	78,659	800	+ 1 %
East Henrietta				
Rochester, 0–19 ...	14,625	14,300	300	− 2 %
" 32–49 ...	11,950	11,575	350	− 3 %
" 49–66 ...	10,700	10,200	500	− 5 %
Total and averages .	37,275	36,075	1200	− 3¼ %

The question of quantities is not the only factor in determining the interval. Where it is important to fit the local conditions, as in a village, or to utilize an old hard foundation, the designer is helped by 50′ sections.

In taking cross-sections the work becomes mechanical, and unless the engineer in charge is unusually alert to all the intermediate changes better results will be obtained by the use of the shorter interval. For these reasons the author believes that a 50′ interval is advisable except on long uniform stretches of road.

A party of three men will run from 4000 to 7000 feet of 50′ cross-sections per day; a party of four men from 5000 to 9000 feet, depending on the country.

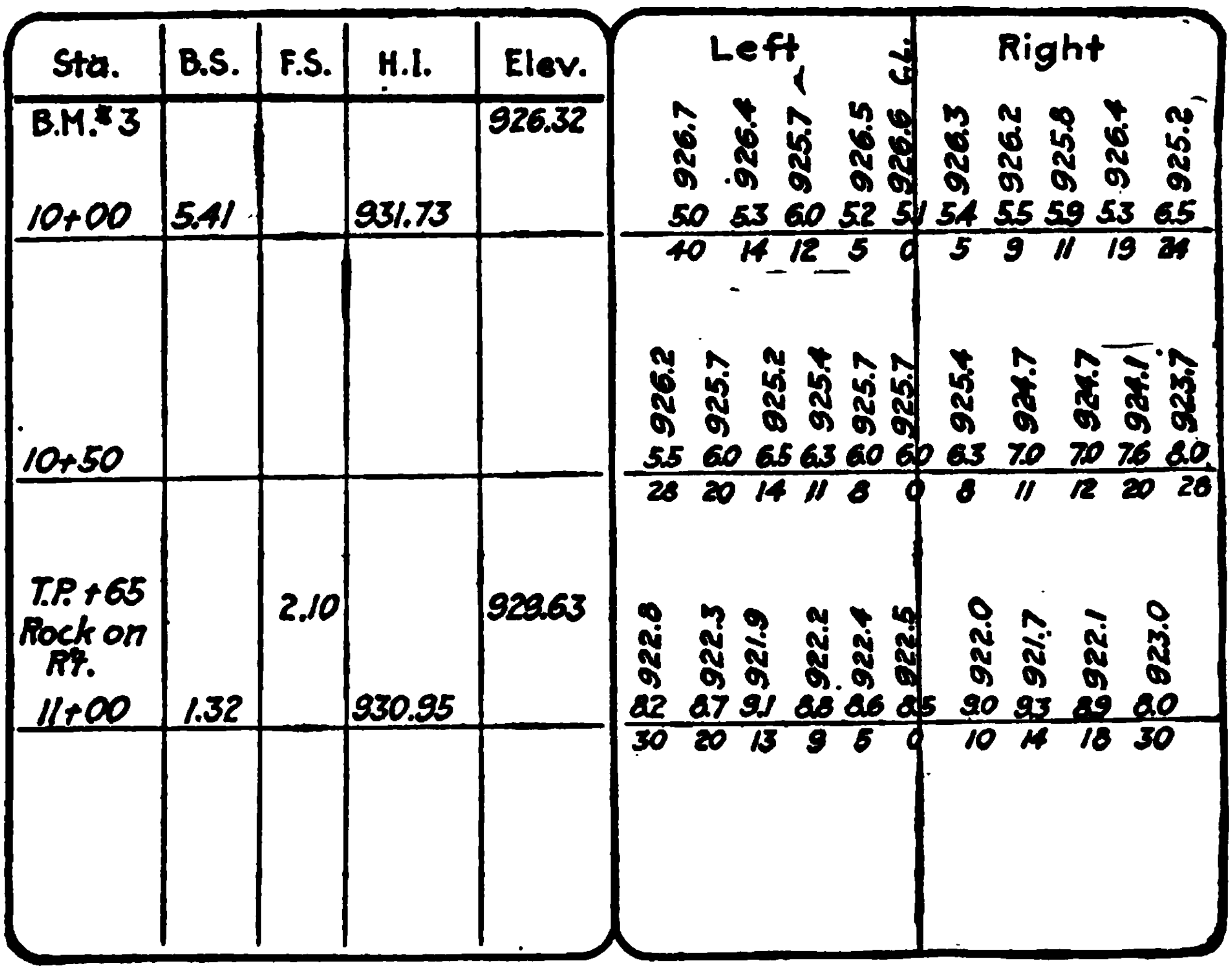


FIG. 64.—Cross-section notes.

DRAINAGE

The drainage notes show the position and size of all the existing culverts; the area of the watersheds draining to them and a recommendation of the size culvert to be built; the location, drainage area, and size of desirable new culverts; the necessity for outlet ditches and their length, if required; the elevation of flood water near streams, and the condition of the abutments and superstructure of long-span bridges. The cross-section levels are supplemented to show these points fully. Where the U. S. geological maps are available the areas of watersheds can be easily determined;

where no such maps have been made the drainage areas can be easily mapped with a small 15″ plane table oriented with a magnetic needle; the distances can be paced and the divides determined with a hand level. One inch to 2000 feet is a convenient scale.

The drainage scheme should be carefully worked out by the Chief of Party, as the possibilities of friction with local people are greater on this part of the design than any other. In the chapter on Drainage this fact was mentioned and designers were cautioned not to use new culverts unless necessary.

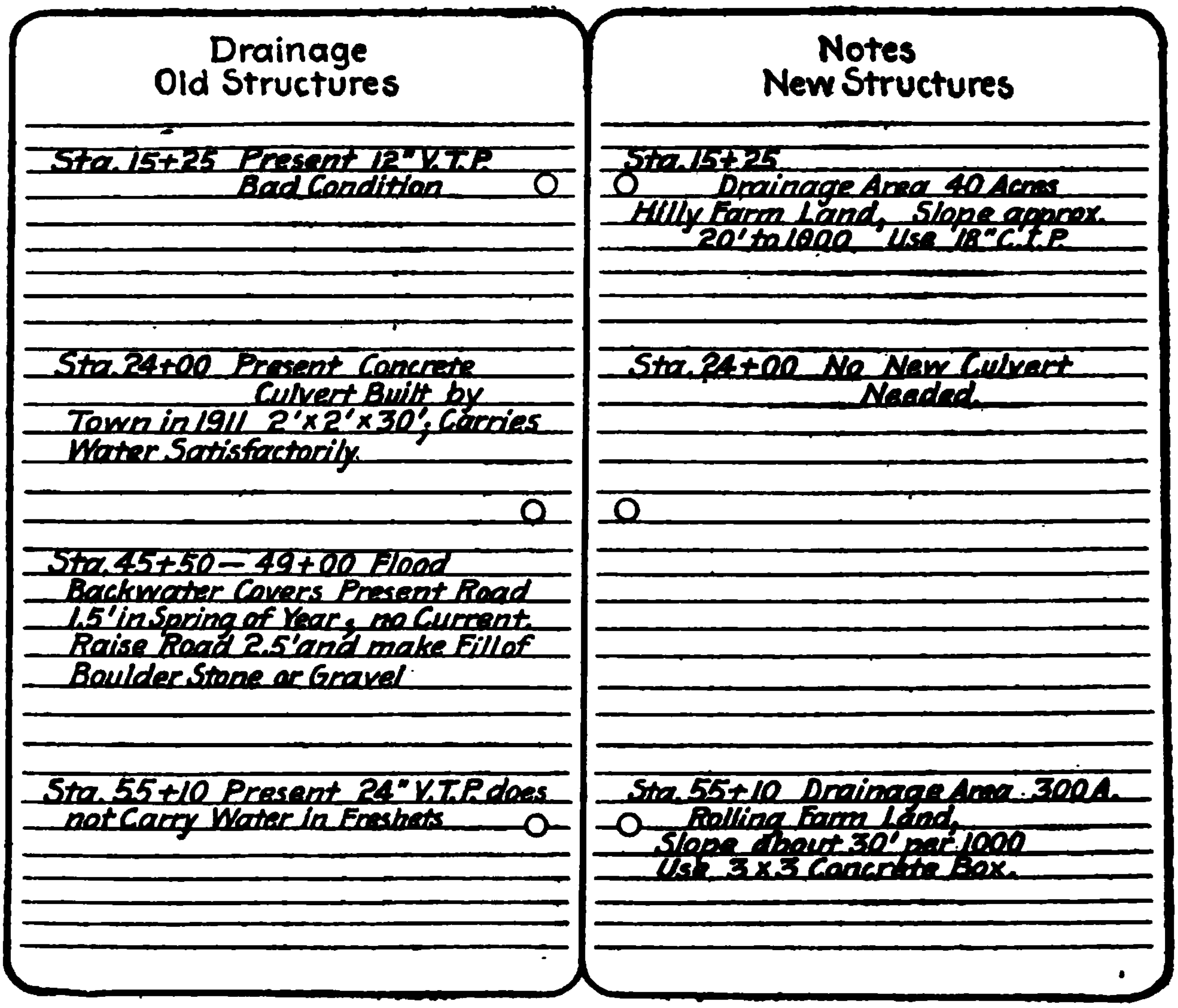


FIG. 65.

TOPOGRAPHY

The topography notes show the features of the adjacent territory that might affect the design. These include the location of buildings, drives, intersecting roads, streams, railroads, poles, trees, sidewalks, crosswalks, and property lines. The names of property owners are recorded.

A simple method of locating these points is to refer them directly to the previously run center line by right-angle offsets; such notes are easily taken and quickly plotted.

In taking the topography the plus stationing along the center line and the offset distances to all points inside of the road fences should be measured by tape to the nearest foot; the distances

to and the dimensions of buildings, etc., outside of these limits, can be paced or estimated; the bearings of the property lines can be read near enough with a pocket compass, except for right-of-way surveys which are described on page 333.

The instruments needed for work of this kind are a pocket compass reading to 2°, steel picket, and metallic tape.

Two experienced men will take from two miles to four miles of topography a day except in villages, where from one-half to a mile is average speed.

Direction and amount of traffic is determined by inspection and inquiry of the residents along the road.

To illustrate the information required, an extract from the survey report of the Fairport Nine Mile Point Road is given below:

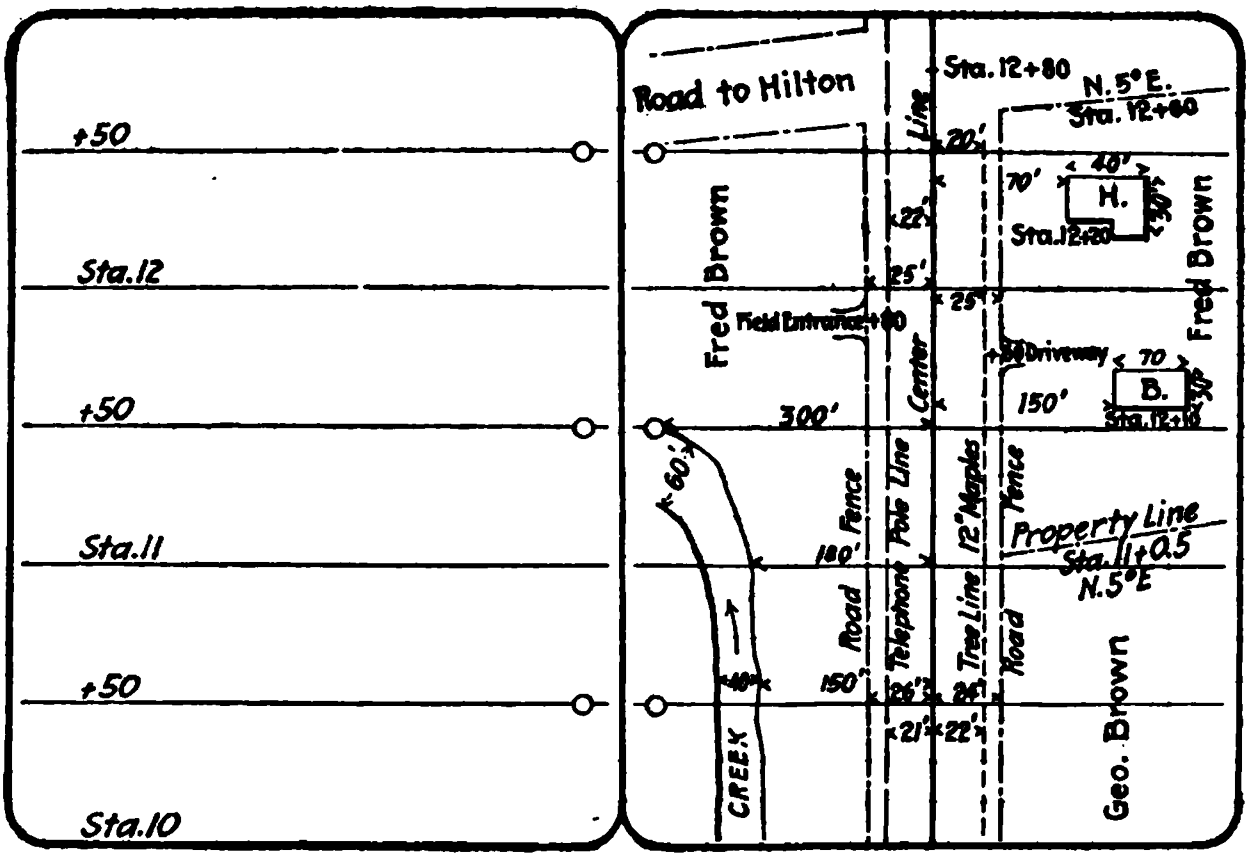


FIG. 66.

Fairport Nine Mile Point Road Traffic Report

Heavy Hauling.—The direction of heavy hauling on this road is approximately as follows:

1. Station No. 195 to station 0 toward Fairport.
2. " " 195 " " 400 " Webster.
3. " " 580 " " 400 " "

This divides the road into three sections for the determination of the ruling grades.

The ruling grades for section 1 will be determined by the hills at station 10 and station 48 and probably will be limited to 5 per cent.

The ruling grade for section 2 will be determined by the knolls at stations 267, 285, and 300.

The ruling grade for section 3 will be determined by the hills at stations 445 and 494.

The team traffic is medium heavy station 90 to station 0; light, station 270 to 90; medium, station 270 to 375; heavy, station 375 to 386; very heavy, equivalent to city street, station 386 to 408; medium heavy, station 408 to 450, and light, station 450 to 580. Macadam construction will not be suitable stations 386 to 408.

The automobile pleasure traffic will be largely through traffic and probably fairly heavy.

FOUNDATION SOILS

The notes on soils show the character, width, and depth of the existing surfacing material and the kind of underlying mate-

Soil Notes				Foundation Recommendations
Sta.	to Sta.	Surface Mat.	Sub Surface	
0	30	Sand & Gravel	Sand & Gravel	Total Thickness Macadam 7"
30	31	Clay & Gravel	Clay 1' down	" " " 12"
31	36	Clay	Clay	" " " 15"
36	40	Gravel 8" deep	Wet Clay	Underdrain on Rt Stone 22" deep
40	41	" 4" "	Clay Loam	Fill at this Point " 9" "

FIG. 67.

rial. This feature of the survey is important, as it governs the thickness of the bottom course, and, to a certain extent, the position of the grade line where an existing solid foundation can be utilized and the thickness of the improved road reduced to a minimum.

Even with a careful soil examination it is impossible to make the design of the foundation definite, as mentioned on page 161, but the quantity of the material that will be needed can be estimated very closely.

The sub-soil can be readily examined by driving a 1½″ or 1″ steel bar to the required depth, which is usually not over 4.0′ to 5.0′ even in cuts, removing the bar and replacing with a ¾″ gas pipe, which is driven a few inches and withdrawn. The core will give a fair idea of the material to be encountered.

Where rock is encountered the elevation of the outcrop is shown, and if the rock underlies the road for any distance within two or three feet of the surface this depth is determined by driving bars. Sample notes below:

Station	Left	Center Line	Right
62	$\frac{3.5'}{20}$	$\frac{2.5'}{00}$	$\frac{0.5'}{20}$
63	$\frac{1.5'}{25}$	$\frac{1.2'}{00}$	$\frac{1.0'}{22}$

The note $\frac{3.5'}{20}$ means that 20′ to the left of the proposed center line of the improvement, the rock is 3.5′ below the present surface; from these notes the rock can be readily plotted on the cross-sections. Its character can be determined from adjacent outcrops, or from test pits, if required.

LOCATION AND CHARACTER OF MATERIALS

The selection of materials and the estimate of the construction cost depend on a knowledge of the available materials and their location relative to the road.

Provided this data has not been well gathered on the Preliminary investigation work it should be obtained at this stage. The methods were described in Chapter on Preliminary Investigation but will be repeated at this point for convenience.

Unloading Points for Freight.—Provided U. S. geological maps are obtainable, the position of sidings may be marked on the sheets. The notes for each siding show its car capacity; whether or not an elevator unloading plant can be erected, and if hand unloading is necessary whether teams can approach from one side or two. They should also show any coal trestles that can be utilized in unloading, and the location and probable cost of any new sidings that will materially reduce the length of the haul. Canal or river unloading points are shown in the same manner.

Sand, Gravel, and Filler Material.—The position of sand and gravel pits and filler material are noted with their cost at the pit; if no local material is available the cost f.o.b. at the nearest siding is given.

Stone Supply.—Provided imported stone is to be used the work is simplified to determining the rate f.o.b. to the various sidings

for the product of the nearest commercial stone-crushing plant that produces a proper grade of stone.

In case local stone is available the location of the quarries or outcrops is shown; the amount of stripping, if any, and the cost of quarry rights. If the estimate will depend upon rock owned by a single person an option is obtained to prevent an exorbitant raise in price.

In the case of field or fence stone a careful estimate is made of the number of yards of boulder stone available, the owners' names, what they will charge for it, the position of the fences or piles relative to the road, or side roads, and if the fences are not abutting on a road or lane the length of haul through fields to

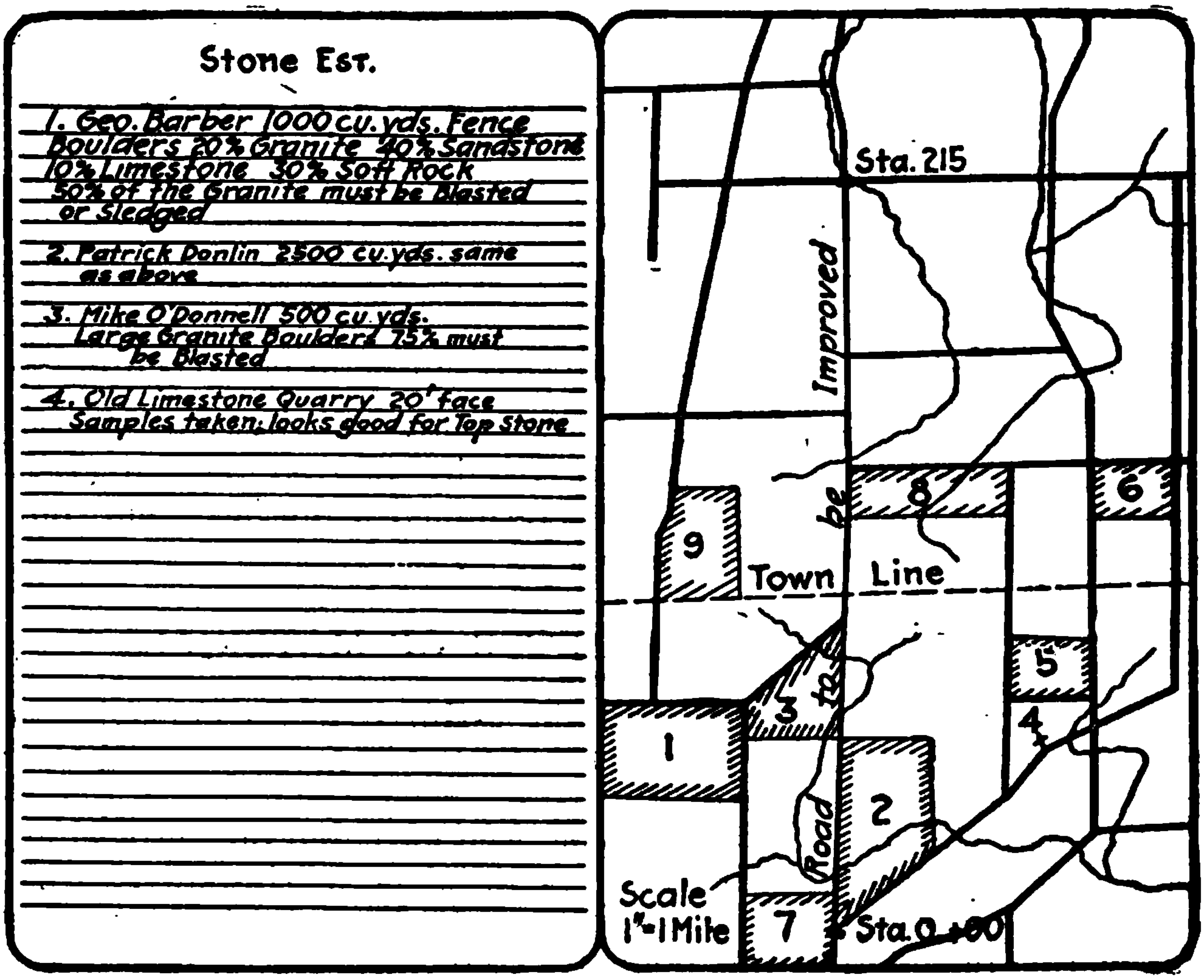


FIG. 68.

the nearest road or lane. As fences are usually a mixture of different kinds of rock, the engineer estimates the percentage of granite, limestone, sandstone, etc., and the percentage that will have to be blasted or sledged in order to be crushed by an ordinary portable crusher. The amount of field stone required per cubic yard of macadam is given in estimates, page 593. If there is a large excess of stone a careful estimate need not be made, only enough data being collected to determine the probable position of the crusher set-ups and the average haul to each set-up. If a sufficient supply is doubtful a close estimate is made as outlined above and options obtained from the various owners.

Samples of the different rocks are tested. (See materials.)

Preliminary surveys of the above description should be made at a speed of from two to four miles per week at a cost of from \$35 to \$70 per mile, allowing \$6 per day for the engineer; \$3.50 for the instrument man; \$2 per man for three laborers; \$1 per day board per man and \$4 per day for livery.

Right-of-way and diversion line surveys are often needed but are usually not made at this time; if the designer believes that additional land must be acquired or that a diversion line is necessary, he indicates the information desired and the surveys are made.

RIGHT-OF-WAY SURVEYS

These surveys are used not only to show the amount of land to be acquired but, also, the damage to property from altering the shape of a field, cutting a farm in two, changing the position of a house or barn relative to the road, etc.

The acreage to be taken is shown by an ordinary land survey in which the road lines, property lines, corners, etc., are located in relation to the proposed center line of the improvement, and their lengths and bearings carefully determined. It is often difficult to locate the road boundaries, as town records are carelessly kept and there is a general tendency to encroach on the road. As the amount paid for new right-of-way is rarely settled on an acreage basis, it is customary to take the existing fence lines as the road line unless it is very evident that the fence has been moved. This produces better feeling on the part of the property owner and does not affect the price paid. The lines between adjoining properties are usually well defined.

In cases where an orchard is damaged the position and size of the trees are noted; where a field or farm is cut the whole field is shown, with the shape and acreage of the pieces remaining after the land actually appropriated has been taken out.

As is usually done in all land surveys, the parcel to be bought is traversed and the survey figured for closure error to insure the description against mistakes.

The standard form of map and description of the N. Y. State Department is shown in the following illustration:

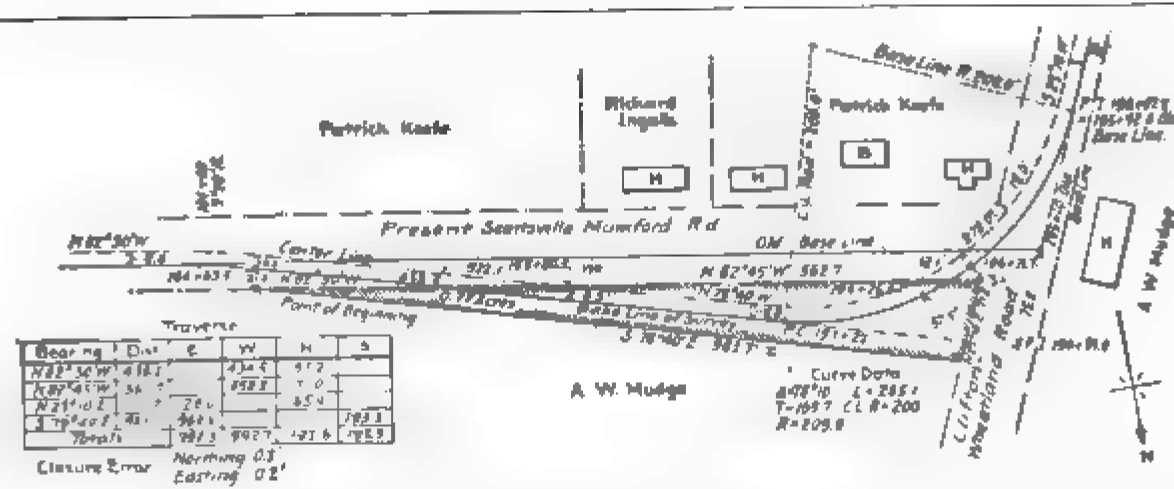


FIG. 69. — Land to be Acquired for the Scottsville-Mumford State Highway, Monroe County: Route No. 16, Section No. 1, from A. W. Mudge.

All that piece or parcel of land situate in the Town of Wheatland, County of Monroe, State of N.Y., for the Scottsville-Mumford State Highway as shown on the accompanying map and described as follows:—

Beginning at a point in the northerly boundary of the existing Scottsville Mumford highway, 21.0 feet northerly, measured at right angles, from station 184+63.5 of the survey base line of the proposed Scottsville-Mumford State Highway (Route No. 16, Section No. 1), and 30.0 feet distant northerly, measured at right angles, from the hereinafter described center line of the said proposed State highway; thence N. 82° 30′ W., along the northerly boundary of the said existing Scottsville Mumford Highway; 438.2 feet, to a point 8.5 feet distant, southerly, measured at right angles, from station 189+00.5 of the said base line, thence N. 82° 45′ W. along the northerly boundary of the said highway, 567.7 feet, to a point 3.1 feet distant northwesterly, measured radially, from station 194+71.7 of the said base line and 12.1 feet distant; measured radially, from the said center line, thence N. 23° 10′ E. along the easterly boundary of the existing Wheatland-Clifton Highway, 71.2 feet to a point 52.3 feet distant northerly, measured radially from station 194+26 of the said base line, thence S. 78° 40′ E. 983.7 ± feet to the point of beginning; being 0.77 acres more or less.

The above mentioned center line is a portion of the center line of the said proposed Scottsville-Mumford State Highway (Route No. 16, Section No. 1) as shown on a map on file in the office of the Clerk of Monroe County, and is described as follows.—

Beginning at a point 9.0 feet distant southerly, measured at right angles from Station 183+00 of the said base line; thence N. 82° 30′ W. 163.5 ft.; thence N. 78° 40′ W. 922.1 feet; thence curving to the left with a radius 200 feet; 272 ± feet to a point 9.0 feet distant southeasterly, measured radially, from Station 196+07.2 of the said base line (= 195+92.0 old base line) thence S. 23° 10′ W.

TABLE 30.[1] HORIZONTAL DISTANCES AND ELEVATIONS FROM STADIA READINGS

	0°		1°		2°		3°	
Minutes	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.
0	100.00	0.00	99.97	1.74	99.88	3.49	99.73	5.23
2	100.00	0.06	99.97	1.80	99.87	3.55	99.72	5.28
4	100.00	0.12	99.97	1.86	99.87	3.60	99.71	5.34
6	100.00	0.17	99.96	1.92	99.87	3.66	99.71	5.40
8	100.00	0.23	99.96	1.98	99.86	3.72	99.70	5.46
10	100.00	0.29	99.96	2.04	99.86	3.78	99.69	5.52
12	100.00	0.35	99.96	2.09	99.85	3.84	99.69	5.57
14	100.00	0.41	99.95	2.15	99.85	3.90	99.68	5.63
16	100.00	0.47	99.95	2.21	99.84	3.95	99.68	5.69
18	100.00	0.52	99.95	2.27	99.84	4.01	99.67	5.75
20	100.00	0.58	99.95	2.33	99.83	4.07	99.66	5.80
22	100.00	0.64	99.94	2.38	99.83	4.13	99.66	5.86
24	100.00	0.70	99.94	2.44	99.82	4.18	99.65	5.92
26	99.99	0.76	99.94	2.50	99.82	4.24	99.64	5.98
28	99.99	0.81	99.93	2.56	99.81	4.30	99.63	6.04
30	99.99	0.87	99.93	2.62	99.81	4.36	99.63	6.09
32	99.99	0.93	99.93	2.67	99.80	4.42	99.62	6.15
34	99.99	0.99	99.93	2.73	99.80	4.48	99.62	6.21
36	99.99	1.05	99.92	2.79	99.79	4.53	99.61	6.27
38	99.99	1.11	99.92	2.85	99.79	4.59	99.60	6.33
40	99.99	1.16	99.92	2.91	99.78	4.65	99.59	6.38
42	99.99	1.22	99.91	2.97	99.78	4.71	99.59	6.44
44	99.98	1.28	99.91	3.02	99.77	4.76	99.58	6.50
46	99.98	1.34	99.90	3.08	99.77	4.82	99.57	6.56
48	99.98	1.40	99.90	3.14	99.76	4.88	99.56	6.61
50	99.98	1.45	99.90	3.20	99.76	4.94	99.56	6.67
52	99.98	1.51	99.89	3.26	99.75	4.99	99.55	6.73
54	99.98	1.57	99.89	3.31	99.74	5.05	99.54	6.78
56	99.97	1.63	99.89	3.37	99.74	5.11	99.53	6.84
58	99.97	1.69	99.88	3.43	99.73	5.17	99.52	6.90
60	99.97	1.74	99.88	3.49	99.73	5.23	99.51	6.96
c = 0.75	0.75	0.01	0.75	0.02	0.75	0.03	0.75	0.05
c = 1.00	1.00	0.01	1.00	0.03	1.00	0.04	1.00	0.06
c = 1.25	1.25	0.02	1.25	0.03	1.25	0.05	1.25	0.08

[1] From "Theory and Practice of Surveying," by Prof. J. B. Johnson, New York: John Wiley & Sons. We are enabled to use this form through the courtesy of Prof. J. B. Johnson.

TABLE 30. HORIZONTAL DISTANCES AND ELEVATIONS FROM STADIA READINGS.—*Continued*

	4°		5°		6°		7°	
Minutes	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.
0	99.51	6.96	99.24	8.68	98.91	10.40	98.51	12.10
2	99.51	7.02	99.23	8.74	98.90	10.45	98.50	12.15
4	99.50	7.07	99.22	8.80	98.88	10.51	98.48	12.21
6	99.49	7.13	99.21	8.85	98.87	10.57	98.47	12.26
8	99.48	7.19	99.20	8.91	98.86	10.62	98.46	12.32
10	99.47	7.25	99.19	8.97	98.85	10.68	98.44	12.38
12	99.46	7.30	99.18	9.03	98.83	10.74	98.43	12.43
14	99.46	7.36	99.17	9.08	98.82	10.79	98.41	12.49
16	99.45	7.42	99.16	9.14	98.81	10.85	98.40	12.55
18	99.44	7.48	99.15	9.20	98.80	10.91	98.39	12.60
20	99.43	7.53	99.14	9.25	98.78	10.96	98.37	12.66
22	99.42	7.59	99.13	9.31	98.77	11.02	98.36	12.72
24	99.41	7.65	99.11	9.37	98.76	11.08	98.34	12.77
26	99.40	7.71	99.10	9.43	98.74	11.13	98.33	12.83
28	99.39	7.76	99.09	9.48	98.73	11.19	98.31	12.88
30	99.38	7.82	99.08	9.54	98.72	11.25	98.29	12.94
32	99.38	7.88	99.07	9.60	98.71	11.30	98.28	13.00
34	99.37	7.94	99.06	9.65	98.69	11.36	98.27	13.05
36	99.36	7.99	99.05	9.71	98.68	11.42	98.25	13.11
38	99.35	8.05	99.04	9.77	98.67	11.47	98.24	13.17
40	99.34	8.11	99.03	9.83	98.65	11.53	98.22	13.22
42	99.33	8.17	99.01	9.88	98.64	11.59	98.20	13.28
44	99.32	8.22	99.00	9.94	98.63	11.64	98.19	13.33
46	99.31	8.28	98.99	10.00	98.61	11.70	98.17	13.39
48	99.30	8.34	98.98	10.05	98.60	11.76	98.16	13.45
50	99.29	8.40	98.97	10.11	98.58	11.81	98.14	13.50
52	99.28	8.45	98.96	10.17	98.57	11.87	98.13	13.56
54	99.27	8.51	98.94	10.22	98.56	11.93	98.11	13.61
56	99.26	8.57	98.93	10.28	98.54	11.98	98.10	13.67
58	99.25	8.63	98.92	10.34	98.53	12.04	98.08	13.73
60	99.24	8.68	98.91	10.40	98.51	12.10	98.06	13.78
c = 0.75	0.75	0.06	0.75	0.07	0.75	0.08	0.74	0.10
c = 1.00	1.00	0.08	0.99	0.09	0.99	0.11	0.99	0.13
c = 1.25	1.25	0.10	1.24	0.11	1.24	0.14	1.24	0.16

TABLE 30. HORIZONTAL DISTANCES AND ELEVATIONS FROM STADIA READINGS.—*Continued*

	8°		9°		10°		11°	
Minutes	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.
0	98.06	13.78	97.55	15.45	96.98	17.10	96.36	18.73
2	98.05	13.84	97.53	15.51	96.96	17.16	96.34	18.78
4	98.03	13.89	97.52	15.56	96.94	17.21	96.32	18.84
6	98.01	13.95	97.50	15.62	96.92	17.26	96.29	18.89
8	98.00	14.01	97.48	15.67	96.90	17.32	96.27	18.95
10	97.98	14.06	97.46	15.73	96.88	17.37	96.25	19.00
12	97.97	14.12	97.44	15.78	96.86	17.43	96.23	19.05
14	97.95	14.17	97.43	15.84	96.84	17.48	96.21	19.11
16	97.93	14.23	97.41	15.89	96.82	17.54	96.18	19.16
18	97.92	14.28	97.39	15.95	96.80	17.59	96.16	19.21
20	97.90	14.34	97.37	16.00	96.78	17.65	96.14	19.27
22	97.88	14.40	97.35	16.06	96.76	17.70	96.12	19.32
24	97.87	14.45	97.33	16.11	96.74	17.76	96.09	19.38
26	97.85	14.51	97.31	16.17	96.72	17.81	96.07	19.43
28	97.83	14.56	97.29	16.22	96.70	17.86	96.05	19.48
30	97.82	14.62	97.28	16.28	96.68	17.92	96.03	19.54
32	97.80	14.67	97.26	16.33	96.66	17.97	96.00	19.59
34	97.78	14.73	97.24	16.39	96.64	18.03	95.98	19.64
36	97.76	14.79	97.22	16.44	96.62	18.08	95.96	19.70
38	97.75	14.84	97.20	16.50	96.60	18.14	95.93	19.75
40	97.73	14.90	97.18	16.55	96.57	18.19	95.91	19.80
42	97.71	14.95	97.16	16.61	96.55	18.24	95.89	19.86
44	97.69	15.01	97.14	16.66	96.53	18.30	95.86	19.91
46	97.68	15.06	97.12	16.72	96.51	18.35	95.84	19.96
48	97.66	15.12	97.10	16.77	96.49	18.41	95.82	20.02
50	97.64	15.17	97.08	16.83	96.47	18.46	95.79	20.07
52	97.62	15.23	97.06	16.88	96.45	18.51	95.77	20.12
54	97.61	15.28	97.04	16.94	96.42	18.57	95.75	20.18
56	97.59	15.34	97.02	16.99	96.40	18.62	95.72	20.23
58	97.57	15.40	97.00	17.05	96.38	18.68	95.70	20.28
60	97.55	15.45	96.98	17.10	96.36	18.73	95.68	20.34
c = 0.75	0.74	0.11	0.74	0.12	0.74	0.14	0.73	0.15
c = 1.00.	0.99	0.15	0.99	0.16	0.98	0.18	0.98	0.20
c = 1.25.	1.23	0.18	1.23	0.21	1.23	0.23	1.22	0.25

TABLE 30. HORIZONTAL DISTANCES AND ELEVATIONS FROM STADIA READINGS.—*Continued*

	12°		13°		14°		15°	
Minutes	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.
0	95.68	20.34	94.94	21.92	94.15	23.47	93.30	25.00
2	95.65	20.39	94.91	21.97	94.12	23.52	93.27	25.05
4	95.63	20.44	94.89	22.02	94.09	23.58	93.24	25.10
6	95.61	20.50	94.86	22.08	94.07	23.63	93.21	25.15
8	95.58	20.55	94.84	22.13	94.04	23.68	93.18	25.20
10	95.56	20.60	94.81	22.18	94.01	23.73	93.16	25.25
12	95.53	20.66	94.79	22.23	93.98	23.78	93.13	25.30
14	95.51	20.71	94.76	22.28	93.95	23.83	93.10	25.35
16	95.49	20.76	94.73	22.34	93.93	23.88	93.07	25.40
18	95.46	20.81	94.71	22.39	93.90	23.93	93.04	25.45
20	95.44	20.87	94.68	22.44	93.87	23.99	93.01	25.50
22	95.41	20.92	94.66	22.49	93.84	24.04	92.98	25.55
24	95.39	20.97	94.63	22.54	93.81	24.09	92.95	25.60
26	95.36	21.03	94.60	22.60	93.79	24.14	92.92	25.65
28	95.34	21.08	94.58	22.65	93.76	24.19	92.89	25.70
30	95.32	21.13	94.55	22.70	93.73	24.24	92.86	25.75
32	95.29	21.18	94.52	22.75	93.70	24.29	92.83	25.80
34	95.27	21.24	94.50	22.80	93.67	24.34	92.80	25.85
36	95.24	21.29	94.47	22.85	93.65	24.39	92.77	25.90
38	95.22	21.34	94.44	22.91	93.62	24.44	92.74	25.95
40	95.19	21.39	94.42	22.96	93.59	24.49	92.71	26.00
42	95.17	21.45	94.39	23.01	93.56	24.55	92.68	26.05
44	95.14	21.50	94.36	23.06	93.53	24.60	92.65	26.10
46	95.12	21.55	94.34	23.11	93.50	24.65	92.62	26.15
48	95.09	21.60	94.31	23.16	93.47	24.70	92.59	26.20
50	95.07	21.66	94.28	23.22	93.45	24.75	92.56	26.25
52	95.04	21.71	94.26	23.27	93.42	24.80	92.53	26.30
54	95.02	21.76	94.23	23.32	93.39	24.85	92.49	26.35
56	94.99	21.81	94.20	23.37	93.36	24.90	92.46	26.40
58	94.97	21.87	94.17	23.42	93.33	24.95	92.43	26.45
60	94.94	21.92	94.15	23.47	93.30	25.00	92.40	26.50
c = 0.75	0.73	0.16	0.73	0.17	0.73	0.19	0.72	0.20
c = 1.00	0.98	0.22	0.97	0.23	0.97	0.25	0.96	0.27
c = 1.25	1.22	0.27	1.21	0.29	1.21	0.31	1.20	0.34

TABLE 30. HORIZONTAL DISTANCES AND ELEVATIONS FROM STADIA READINGS.—*Continued*

	16°		17°		18°		19°	
Minutes	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.
0	92.40	26.50	91.45	27.96	90.45	29.39	89.40	30.78
2	92.37	26.55	91.42	28.01	90.42	29.44	89.36	30.83
4	92.34	26.59	91.39	28.06	90.38	29.48	89.33	30.87
6	92.31	26.64	91.35	28.10	90.35	29.53	89.29	30.92
8	92.28	26.69	91.32	28.15	90.31	29.58	89.26	30.97
10	92.25	26.74	91.29	28.20	90.28	29.62	89.22	31.01
12	92.22	26.79	91.26	28.25	90.24	29.67	89.18	31.06
14	92.19	26.84	91.22	28.30	90.21	29.72	89.15	31.10
16	92.15	26.89	91.19	28.34	90.18	29.76	89.11	31.15
18	92.12	26.94	91.16	28.39	90.14	29.81	89.08	31.19
20	92.09	26.99	91.12	28.44	90.11	29.86	89.04	31.24
22	92.06	27.04	91.09	28.49	90.07	29.90	89.00	31.28
24	92.03	27.09	91.06	28.54	90.04	29.95	88.96	31.33
26	92.00	27.13	91.02	28.58	90.00	30.00	88.93	31.38
28	91.97	27.18	90.99	28.63	89.97	30.04	88.89	31.42
30	91.93	27.23	90.96	28.68	89.93	30.09	88.86	31.47
32	91.90	27.28	90.92	28.73	89.90	30.14	88.82	31.51
34	91.87	27.33	90.89	28.77	89.86	30.19	88.78	31.56
36	91.84	27.38	90.86	28.82	89.83	30.23	88.75	31.60
38	91.81	27.43	90.82	28.87	89.79	30.28	88.71	31.65
40	91.77	27.48	90.79	28.92	89.76	30.32	88.67	31.69
42	91.74	27.52	90.76	28.96	89.72	30.37	88.64	31.74
44	91.71	27.57	90.72	29.01	89.69	30.41	88.60	31.78
46	91.68	27.62	90.69	29.06	89.65	30.46	88.56	31.83
48	91.65	27.67	90.66	29.11	89.61	30.51	88.53	31.87
50	91.61	27.72	90.62	29.15	89.58	30.55	88.49	31.92
52	91.58	27.77	90.59	29.20	89.54	30.60	88.45	31.96
54	91.55	27.81	90.55	29.25	89.51	30.65	88.41	32.01
56	91.52	27.86	90.52	29.30	89.47	30.69	88.38	32.05
58	91.48	27.91	90.48	29.34	89.44	30.74	88.34	32.09
60	91.45	27.96	90.45	29.39	89.40	30.78	88.30	32.14
c = 0.75.	0.72	0.21	0.72	0.23	0.71	0.24	0.71	0.25
c = 1.00.	0.96	0.28	0.95	0.30	0.95	0.32	0.94	0.33
c = 1.25.	1.20	0.35	1.19	0.38	1.19	0.40	1.18	0.42

TABLE 30. HORIZONTAL DISTANCES AND ELEVATIONS FROM STADIA READINGS.—*Continued*

·	20°		21°		22°		23°	
Minutes.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.
0	88.30	32.14	87.16	33.46	85.97	34.73	84.73	35.97
2	88.26	32.18	87.12	33.50	85.93	34.77	84.69	36.01
4	88.23	32.23	87.08	33.54	85.89	34.82	84.65	36.05
6	88.19	32.27	87.04	33.59	85.85	34.86	84.61	36.09
8	88.15	32.32	87.00	33.63	85.80	34.90	84.57	36.13
10	88.11	32.36	86.96	33.67	85.76	34.94	84.52	36.17
12	88.08	32.41	86.92	33.72	85.72	34.98	84.48	36.21
14	88.04	32.45	86.88	33.76	85.68	35.02	84.44	36.25
16	88.00	32.49	86.84	33.80	85.64	35.07	84.40	36.29
18	87.96	32.54	86.80	33.84	85.60	35.11	84.35	36.33
20	87.93	32.58	86.77	33.89	85.56	35.15	84.31	36.37
22	87.89	32.63	86.73	33.93	85.52	35.19	84.27	36.41
24	87.85	32.67	86.69	33.97	85.48	35.23	84.23	36.45
26	87.81	32.72	86.65	34.01	85.44	35.27	84.18	36.49
28	87.77	32.76	86.61	34.06	85.40	35.31	84.14	36.53
30	87.74	32.80	86.57	34.10	85.36	35.36	84.10	36.57
32	87.70	32.85	86.53	34.14	85.31	35.40	84.06	36.61
34	87.66	32.89	86.49	34.18	85.27	35.44	84.01	36.65
36	87.62	32.93	86.45	34.23	85.23	35.48	83.97	36.69
38	87.58	32.98	86.41	34.27	85.19	35.52	83.93	36.73
40	87.54	33.02	86.37	34.31	85.15	35.56	83.89	36.77
42	87.51	33.07	86.33	34.35	85.11	35.60	83.84	36.80
44	87.47	33.11	86.29	34.40	85.07	35.64	83.80	36.84
46	87.43	33.15	86.25	34.44	85.02	35.68	83.76	36.88
48	87.39	33.20	86.21	34.48	84.98	35.72	83.72	36.92
50	87.35	33.24	86.17	34.52	84.94	35.76	83.67	36.96
52	87.31	33.28	86.13	34.57	84.90	35.80	83.63	37.00
54	87.27	33.33	86.09	34.61	84.86	35.85	83.59	37.04
56	87.24	33.37	86.05	34.65	84.82	35.89	83.54	37.08
58	87.20	33.41	86.01	34.69	84.77	35.93	83.50	37.12
60	87.16	33.46	85.97	34.73	84.73	35.97	83.46	37.16
c = 0.75 .	0.70	0.26	0.70	0.27	0.69	0.29	0.69	0.30
c = 1.00 .	0.94	0.35	0.93	0.37	0.92	0.38	0.92	0.40
c = 1.25 .	1.17	0.44	1.16	0.46	1.15	0.48	1.15	0.50

TABLE 30. HORIZONTAL DISTANCES AND ELEVATIONS FROM STADIA READINGS.—*Continued*

	24°		25°		26°		27°	
Minutes	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff Elev.	Hor. Dist.	Diff. Elev.
0	83.46	37.16	82.14	38.30	80.78	39.40	79.39	40.45
2	83.41	37.20	82.09	38.34	80.74	39.44	79.34	40.49
4	83.37	37.23	82.05	38.38	80.69	39.47	79.30	40.52
6	83.33	37.27	82.01	38.41	80.65	39.51	79.25	40.55
8	83.28	37.31	81.96	38.45	80.60	39.54	79.20	40.59
10	83.24	37.35	81.92	38.49	80.55	39.58	79.15	40.62
12	83.20	37.39	81.87	38.53	80.51	39.61	79.11	40.66
14	83.15	37.43	81.83	38.56	80.46	39.65	79.06	40.69
16	83.11	37.47	81.78	38.60	80.41	39.69	79.01	40.72
18	83.07	37.51	81.74	38.64	80.37	39.72	78.96	40.76
20	83.02	37.54	81.69	38.67	80.32	39.76	78.92	40.79
22	82.98	37.58	81.65	38.71	80.28	39.79	78.87	40.82
24	82.93	37.62	81.60	38.75	80.23	39.83	78.82	40.86
26	82.89	37.66	81.56	38.78	80.18	39.86	78.77	40.89
28	82.85	37.70	81.51	38.82	80.14	39.90	78.73	40.92
30	82.80	37.74	81.47	38.86	80.09	39.93	78.68	40.96
32	82.76	37.77	81.42	38.89	80.04	39.97	78.63	40.99
34	82.72	37.81	81.38	38.93	80.00	40.00	78.58	41.02
36	82.67	37.85	81.33	38.97	79.95	40.04	78.54	41.06
38	82.63	37.89	81.28	39.00	79.90	40.07	78.49	41.09
40	82.58	37.93	81.24	39.04	79.86	40.11	78.44	41.12
42	82.54	37.96	81.19	39.08	79.81	40.14	78.39	41.16
44	82.49	38.00	81.15	39.11	79.76	40.18	78.34	41.19
46	82.45	38.04	81.10	39.15	79.72	40.21	78.30	41.22
48	82.41	38.08	81.06	39.18	79.67	40.24	78.25	41.26
50	82.36	38.11	81.01	39.22	79.62	40.28	78.20	41.29
52	82.32	38.15	80.97	39.26	79.58	40.31	78.15	41.32
54	82.27	38.19	80.92	39.29	79.53	40.35	78.10	41.35
56	82.23	38.23	80.87	39.33	79.48	40.38	78.06	41.39
58	82.18	38.26	80.83	39.36	79.44	40.42	78.01	41.42
60	82.14	38.30	80.78	39.40	79.39	40.45	77.96	41.45
c = 0.75	0.68	0.31	0.68	0.32	0.67	0.33	0.66	0.35
c = 1.00	0.91	0.41	0.90	0.43	0.89	0.45	0.89	0.46
c = 1.25	1.14	0.52	1.13	0.54	1.12	0.56	1.11	0.58

TABLE 30. HORIZONTAL DISTANCES AND ELEVATIONS FROM STADIA READINGS.—*Concluded*

	28°		29°		30°	
Minutes	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.	Hor. Dist.	Diff. Elev.
0	77.96	41.45	76.50	42.40	75.00	43.30
2	77.91	41.48	76.45	42.43	74.95	43.33
4	77.86	41.52	76.40	42.46	74.90	43.36
6	77.81	41.55	76.35	42.49	74.85	43.39
8	77.77	41.58	76.30	42.53	74.80	43.42
10	77.72	41.61	76.25	42.56	74.75	43.45
12	77.67	41.65	76.20	42.59	74.70	43.47
14	77.62	41.68	76.15	42.62	74.65	43.50
16	77.57	41.71	76.10	42.65	74.60	43.53
18	77.52	41.74	76.05	42.68	74.55	43.56
20	77.48	41.77	76.00	42.71	74.49	43.59
22	77.42	41.81	75.95	42.74	74.44	43.62
24	77.38	41.84	75.90	42.77	74.39	43.65
26	77.33	41.87	75.85	42.80	74.34	43.67
28	77.28	41.90	75.80	42.83	74.29	43.70
30	77.23	41.93	75.75	42.86	74.24	43.73
32	77.18	41.97	75.70	42.89	74.19	43.76
34	77.13	42.00	75.65	42.92	74.14	43.79
36	77.09	42.03	75.60	42.95	74.09	43.82
38	77.04	42.06	75.55	42.98	74.04	43.84
40	76.99	42.09	75.50	43.01	73.99	43.87
42	76.94	42.12	75.45	43.04	73.93	43.90
44	76.89	42.15	75.40	43.07	73.88	43.93
46	76.84	42.19	75.35	43.10	73.83	43.95
48	76.79	42.22	75.30	43.13	73.78	43.98
50	76.74	42.25	75.25	43.16	73.73	44.01
52	76.69	42.28	75.20	43.18	73.68	44.04
54	76.64	42.31	75.15	43.21	73.63	44.07
56	76.59	42.34	75.10	43.24	73.58	44.09
58	76.55	42.37	75.05	43.27	73.52	44.12
60	76.50	42.40	75.00	43.30	73.47	44.15
c = 0.75..	0.66	0.36	0.65	0.37	0.65	0.38
c = 1.00..	0.88	0.48	0.87	0.49	0.86	0.51
c = 1.25..	1.10	0.60	1.09	0.62	1.08	0.64

Diversion Line Surveys.—Where there is no doubt as to the grade to be adopted, or the alignment to be used, the location is made directly in the field and the center line is run and the cross-sections taken in the same manner as for a preliminary survey. If, however, the country is badly cut up and it is difficult to make a field location direct, a transit stadia survey is made covering the territory that will include all the possible locations and from the resulting contour map the different locations are projected and approximate estimates figured. The adopted line is then run in the field, cross-sections taken in the usual manner and an accurate estimate made. This method is used so seldom that the author does not feel justified in giving much space to the theory of stadia measurements or the methods of stadia surveys (see page 416). If the reader is not familiar with this class of work he is referred to the standard works on surveying.

A convenient scale for a contour map for the projection work mentioned above is 1″ = 20′ with a contour interval of 1′ to 5′, depending on the country. Table 30 is useful for reducing stadia notes. For a small number of shots this table and a slide rule will answer the purpose; for any extended amount of work a stadia reduction diagram or Noble & Casgrain's tables are recommended. If the stadia work is well done very satisfactory projections can be made.

ADJUSTMENT OF INSTRUMENTS

Wye Level.—*To Make the Line of Collimation Parallel to the Telescope Rings.*—Level the instrument roughly. Loosen the Y clamps so the telescope can turn freely in them; clamp the horizontal motion and by means of the leveling screws and tangent motion bring the intersection of the cross hairs on some well defined point. Then, without lifting from the Ys, turn the telescope over 180° watching to see if the cross wires remain on the point during the operation; if they do the adjustment is correct; if they do not, correct ½ the apparent error for both vertical and horizontal wires by means of the cross hair ring, adjusting screws, and repeat until the wires remain on the point for a complete revolution.

To Make the Longitudinal Axis of the Level Bubble Parallel to the Plane of the Line of Collimation.—Level the machine over either pair of leveling screws; unclamp the Ys; rotate the telescope in the Ys until the bubble tube is on one side of the bar. If the bubble remains in the center the adjustment is correct. If it runs from the center bring it to its correct position by means of the sidewise adjusting screw at one end of the bubble case.

To Make the Bubble Parallel to the Rings and Line of Collimation.—Level the machine; unclamp the Ys; lift the telescope carefully from the Ys and reverse end for end; if the bubble runs to the center after the telescope has been reversed the adjustment is correct; if not, correct ½ the error by means of the adjusting nuts on the

bubble case and ½ the error with the leveling screws and repeat the test until the bubble remains in the center.

To Adjust the Ys so the Level Bubble Will Be at Right Angles to the Axis of the Instrument.—Level the machine approximately over both sets of screws; level carefully over one set; rotate on the spindle 180°; if the bubble remains in the center the adjustment is correct; if not, correct ½ the error by means of the adjusting nuts on the Ys and ½ by the leveling screws. Repeat until the bubble remains in the center when reversed over either pair of leveling screws.

To Test the Horizontal Wire.—Be sure that the pin in the Y clamp is in the notch of the telescope ring to keep the telescope from rotating; level the machine and compare the horizontal wire with any level line; if the wire is not level loosen the cross wire ring and turn to the correct position. Adjust again for collimation and the level adjustments are complete.

Dumpy Level.—*To Make the Bubble Perpendicular to the Axis of the Instrument.*—Level the machine roughly over both sets of leveling screws and carefully over one set; rotate on the pinion 180°; if the bubble stays in the center the adjustment is correct; if not, correct ½ the error by means of the bubble adjusting nut and ½ by the leveling screws, and repeat until correct.

To Make the Horizontal Line of Collimation Parallel to the Level Bubble.—Level the machine; drive a stake about 150′ or 200′ from the instrument and set the level rod target by the horizontal wire; rotate the instrument 180° and set another stake at the same distance from the machine as the first one; drive it until a rod reading taken on it is the same as the reading on the first stake. These stakes will then be level even though the machine is out of adjustment. Then set the level up near one of the stakes; level carefully and take rod readings on both; if these readings are the same the level is in adjustment; if not, correct the position of the horizontal wire by means of the cross wire ring screws until the readings on both stakes are the same.

Test the horizontal wire on a level line in the same manner as for the Y level.

Transit.—*Plate Levels.*—Level the machine with each plate level bubble parallel to one set of leveling screws; rotate on the spindle 180°; if the bubbles remain in the center the adjustment is correct; if not, correct ½ the error with the bubble adjusting screws and ½ with the leveling screws. Repeat until correct.

Line of Collimation, Ordinary Distances.—Level the machine; clamp the horizontal motion; with the slow motion screw, set the vertical cross wire on some well-defined point 500 or 600 feet away; transit the telescope and set a mark the same distance in the opposite direction; then rotate the machine on the spindle, set on the first mark and transit the telescope; if the vertical wire strikes the second point the adjustment is correct; if not, correct ¼ the error by means of cross wire ring adjusting screws and repeat until correct.

To Make the Standards the Same Height.—Level the machine carefully; set the vertical wire on some well defined point as high as can be seen; bring the telescope down and set a point; rotate the machine 180°; transit the telescope set on the low point and raise the telescope; if the wire bisects the original high point the adjustment is correct; if not, correct ½ the error by means of the standard adjusting screw.

Test the vertical wire by means of a plumb line to see that it is vertical; if not, loosen the cross hair ring and turn to the correct position; test again for collimation.

If the transit is to be used as a level make the level bubble parallel to the horizontal wire by the two-peg method in the same manner as described for the Dumpy level.

EXPLANATION OF CURVE TABLES AND DEVELOPMENT OF CURVE FORMULÆ

Curves for roadwork need not be as carefully worked out as in railroad surveying. Except for long curves the external is usually measured and the curve run in by the eye, and for this reason many of the tables given in the railway field manuals are omitted and those used are tabulated in a different form.

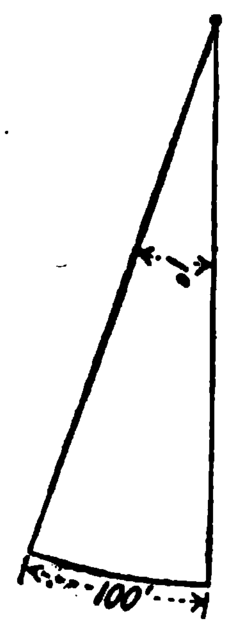


FIG. 70.

Table 31, Radii of Curves.—The curve radii are computed on a basis of 5730 feet as the radius of a one-degree curve and are inversely proportional to the degree of curvature; they are tabulated to the nearest 0.1′. The usual columns showing logarithm of radius, tangent offset and middle ordinate are replaced by the deflection angle per foot of arc, per 25′ of arc, and per 50′ of arc, which saves considerable time in the computation of deflections. These values are tabulated only for even degree, twenty-minute, thirty-minute, and forty-minute curves, as there is always sufficient leeway both in the external and tangent to select a suitable curve from this list.

Table 32, Functions of 1° Curve.—Column 1 gives the central angle Δ for every 10 minutes from 0° to 4° every minute 4° to 100°, and every 10 minutes 100° to 120°.

Column 2 gives the same central angle as in column 1 expressed in decimals of a degree. This simplifies figuring the curve length.

Columns 3 and 4 give the tangent and external for the central angles of column 1 to the nearest 0.1′. By the use of the chord lengths recommended at the top of each page of this table no correction need be made for tangent length or external distance of any desired curve, figured by dividing the value given in the table by the degree of curvature required.

The error that is introduced by the use of these chords is less than 0.1′ per 100′, which is the allowable limit of error in chaining center line.

For the convenience of readers not familiar with the theory of curves and the computation of curve notes, the following brief demonstration is made:

RADII OF CURVES AND DEGREE OF CURVATURE

A one-degree curve is defined as a curve having such a radius that 100 feet of arc will subtend a one-degree central angle.

There are 360° of central angle for a complete circle. The circumference of a circle is expressed by the formula $2\pi R$. Therefore the radius of a one-degree curve is determined by the formulæ

$$2\pi R = 360 \times 100$$

$$R = \frac{36{,}000}{2\pi} = \frac{36{,}000}{2(3.14159)} = 5729.6 \text{ feet} \tag{1}$$

TABLE 31. RADII AND DEFLECTIONS

Figured on a basis of R = 5730′ for a 1° curve.

Degree of Curve	Radius of Curve	Deflection per foot of Arc	Deflection per 25′ of Arc		Deflection per 50′ of Arc	
	Feet	Minutes	Deg.	Minutes	Deg.	Minutes
0° 30′ ..	11,460.0	00.15	—	—	0	07.5
0° 40′ ..	8.595.0	00.2	—	—	0	10.0
0° 50′ ..	6,876.0	00.25	—	—	0	12.5
1° 00′ ..	5,730.0	00.3	—	—	0	15.0
1° 20′ ..	4,297.5	00.4	—	—	0	20.0
1° 30′ ..	3,820.0	00.45	—	—	0	22.5
1° 40′ ..	3,438.0	00.5	—	—	0	25.0
2° 00′ ..	2,865.0	00.6	—	—	0	30.0
2° 20′ ..	2,455.7	00.7	—	—	0	35.0
2° 30′ ..	2,292.0	00.75	—	—	0	37.5
2° 40′ ..	2,148.8	00.8	—	—	0	40.0
3° 00′ ..	1,910.0	00.9	—	—	0	45.0

TABLE 31.—*Continued*

Degree of Curve	Radius of Curve	Deflection per foot of Arc	Deflection per 25′ of Arc		Deflection per 50′ of Arc	
	Feet	Minutes	Deg.	Minutes	Deg.	Minutes
3° 20′ ..	1,719.0	01.0	—	—	0	50.0
3° 30′ ..	1,637.1	01.05	—	—	0	52.5
3° 40′ ..	1,562.7	01.1	—	—	0	55.0
4° 00′ ..	1,432.5	01.2	—	—	1	00.0
4° 20′ ..	1,322.3	01.3	—	—	1	05.0
4° 30′ ..	1,273.3	01.35	—	—	1	07.5
4° 40′ ..	1,227.9	01.4	—	—	1	10.0
5° 00′ ..	1,146.0	01.5	—	—	1	15.0
5° 30′ ..	1,041.8	01.65	—	—	1	22.5
6° 00′ ..	955.0	01.8	—	—	1	30.0
6° 30′ .	881.5	01.95	—	—	1	37.5
7° 00′ .	818.6	02.1	—	—	1	45.0
7° 30′ ..	764.0	02.25	—	—	1	52.5
8° 00′ ..	716.3	02.4	—	—	2	00.0
8° 30′ ..	674.1	02.55	—	—	2	07.5
9° 00′ ..	636.6	02.7	—	—	2	15.0
9° 30′ ..	603.2	02.85	—	—	2	22.5
10° 00′ ..	573.0	03.0	—	—	2	30.0
10° 30′ ..	545.7	03.15	—	—	2	37.5
11° 00′ ..	520.9	03.3	—	—	2	45.0
11° 30′ ..	498.3	03.45	—	—	2	52.5
12° 00′ ..	477.5	03.6	—	—	3	00.0
12° 30′ ..	458.4	03.75	—	—	3	07.5
13° 00′ ..	440.8	03.9	—	—	3	15.0
13° 30′ ..	424.4	04.05	—	—	3	22.5
14° 00′ ..	409.3	04.2	—	—	3	30.0
14° 30′ ..	395.2	04.35	—	—	3	37.5
15° 00′ ..	382.0	04.5	—	—	3	45.0
15° 30′ ..	369.6	04.65	—	—	3	52.5
16° 00′ ..	358.1	04.8	2	00.0	4	00.0
16° 30′ ..	347.3	04.95	2	03.8	4	07.5
17° 00′ ..	337.0	05.1	2	07.5	4	15.0
17° 30′ ..	327.4	05.25	2	11.2	4	22.5
18° 00′ ..	318.3	05.4	2	15.0	4	30.0
18° 30′ ..	309.7	05.55	2	18.7	4	37.5

TABLE 31.—*Continued*

Degree of Curve	Radius of Curve	Deflection per ft. of Arc	Deflection per 25′ of Arc		Deflection per 50′ of Arc	
		Minutes	Degree	Minutes		
19° 00′	301.6	05.7	2	22.5		
19° 30′	293.8	05.85	2	26.2		
20° 00′	286.5	06.0	2	30.0		
20° 30′	279.5	06.15	2	33.7		
21° 00′	272.9	06.30	2	37.5		
21° 30′	266.5	06.45	2	41.2		
22° 00′	260.5	06.6	2	45.0		
22° 30′	254.7	06.75	2	48.7		
23° 00′	249.1	06.9	2	52.5		
23° 30′	243.8	07.05	2	56.2		
24° 00′	238.8	07.2	3	00.0		
24° 30′	233.9	07.35	3	03.7		
25° 00′	229.2	07.5	3	07.5		
26° 00′	220.4	07.8	3	15.0		
27° 00′	212.2	08.1	3	22.5		
28° 00′	204.6	08.4	3	30.0		
29° 00′	197.6	08.7	3	37.5		
30° 00′	191.0	09.0	3	45.0	Deflection per 10′ of Arc	
31° 00′	184.8	09.3	3	52.5		
32° 00′	179.1	09.6	4	00.0	1°	36′
33° 00′	173.6	09.9	—	—	1°	39′
34° 00′	168.5	10.2	—	—	1°	42′
35° 00′	163.7	10.5	—	—	1°	45′
36° 00′	159.2	10.8	—	—	1°	48′
37° 00′	154.9	11.1	—	—	1°	51′
38° 00′	150.8	11.4	—	—	1°	54′
39° 00′	146.9	11.7	—	—	1°	57′
40° 00′	143.2	12.0	—	—	2°	00′
42° 00′	136.4	12.6	—	—	2°	06′
44° 00′	130.2	13.2	—	—	2°	12′
46° 00′	124.6	13.8	—	—	2°	18′
48° 00′	119.4	14.4	—	—	2°	24′
50° 00′	114.6	15.0	—	—	2°	30′
52° 00′	110.2	15.6	—	—	2°	36′
54° 00′	106.1	16.2	—	—	2°	42′
56° 00′	102.3	16.8	—	—	2°	48′

For all practical purposes the value of 5730 can be used.

In the same manner a two-degree curve is one having such a radius that 100 feet of arc will subtend two degrees of central angle, and its radius is

$$2\pi R = \frac{360}{2} \times 100$$

$$R = \frac{18{,}000}{2\pi}$$

or ½ of the radius of a one-degree curve.
The radius of a three-degree curve will be ⅓ of 5730.
The radius of a four-degree curve will be ¼ of 5730.

The formula for the radius of any degree of curve is therefore

$$R = \frac{5730}{D} \qquad (2)$$

The degree of curvature for any specified radius is therefore

$$D = \frac{5730}{R} \qquad (3)$$

In general the degree of curvature is expressed by the central angle subtended by 100 feet of arc, and the radius for that degree of curve is found by dividing 5730 feet, the radius of a one-degree curve, by the degree of curve desired expressed in degrees and decimals of a degree. That is, if the radius of a 3° 30′ curve is wanted, divide 5730 by 3.5, which equals 1637.1′. The radii given in Table 31 are computed in this manner.

Length of Curve.—For a 5° curve a central angle of 5° subtends 100′ of arc; a central angle of 10°, 200′ of arc; a central angle of 12° 30′, 250′ of arc. That is, for a specified central angle the length of any specified curve equals that central angle expressed in degrees and decimals of a degree divided by the degree of curve expressed in degrees and decimals multiplied by 100; *i.e.*, the length of a 10° 15′ curve for a central angle of 20° 45′ $= \frac{20.75}{10.25} \times 100' =$ 202.4′ and is expressed by the formula (continued on page 376)

TABLE 32. FUNCTIONS OF A ONE-DEGREE CURVE FIGURED ON A BASIS OF $R = 5730'$ AND TABULATED TO TENTHS OF FEET

Use 100′ chords up to 8° Curves
Use 50′ chords up to 16° Curves
Use 25′ chords up to 32° Curves
Use 10′ chords above 32° Curves

Minutes	0°		1°		2°		3°		Minutes
	Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	
0	0.0	0.0	0.2	50.0	0.9	100.0	2.0	150.1	0
10	0.0	8.3	0.3	58.3	1.0	108.4	2.2	158.4	10
20	0.0	16.7	0.4	66.7	1.2	116.7	2.4	166.8	20
30	0.1	25.0	0.5	75.0	1.4	125.0	2.7	175.1	30
40	0.1	33.3	0.6	83.3	1.6	133.4	2.9	183.4	40
50	0.2	41.7	0.7	91.7	1.8	141.7	3.2	191.7	50
60	0.2	50.0	0.9	100.0	2.0	150.1	3.5	200.1	60

Use 100′ Chords up to 8° Curves   Use 25′ Chords up to 32° Curves
Use 50′ Chords up to 16° Curves   Use 10′ Chords above 32° Curves

Minutes	Dec. of Degree	12°		13°		14°		15°		Minutes
		Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	
0	.0000	31.6	602.2	37.1	652.9	43.0	703.5	49.4	754.4	0
1	.0167	31.7	603.1	37.2	653.7	43.1	704.4	49.6	755.2	1
2	.0333	31.7	603.9	37.3	654.6	43.2	705.2	49.7	756.1	2
3	.0500	31.8	604.7	37.4	655.4	43.3	706.1	49.8	756.9	3
4	.0667	31.9	605.6	37.5	656.3	43.4	706.9	49.9	757.7	4
5	.0833	32.0	606.4	37.6	657.1	43.5	707.8	50.0	758.6	5
6	.1000	32.1	607.3	37.7	657.9	43.7	708.6	50.1	759.4	6
7	.1167	32.2	608.1	37.7	658.8	43.8	709.5	50.2	760.3	7
8	.1333	32.3	609.0	37.8	659.6	43.9	710.3	50.3	761.1	8
9	.1500	32.4	609.8	37.9	660.5	44.0	711.2	50.5	762.0	9
10	.1667	32.5	610.7	38.0	661.3	44.1	712.0	50.6	762.8	10
11	.1833	32.5	611.5	38.1	662.2	44.2	712.9	50.7	763.7	11
12	.2000	32.6	612.4	38.2	663.0	44.3	713.7	50.8	764.5	12
13	.2167	32.7	613.2	38.3	663.8	44.4	714.6	50.9	765.4	13
14	.2333	32.8	614.0	38.4	664.7	44.5	715.4	51.0	766.2	14
15	.2500	32.9	614.9	38.5	665.5	44.6	716.3	51.1	767.1	15
16	.2667	33.0	615.7	38.6	666.4	44.7	717.1	51.2	767.9	16
17	.2833	33.1	616.6	38.7	667.2	44.8	718.0	51.3	768.8	17
18	.3000	33.2	617.4	38.8	668.1	44.9	718.8	51.5	769.6	18
19	.3167	33.3	618.3	38.9	668.9	45.0	719.6	51.6	770.5	19
20	.3333	33.4	619.1	39.0	669.8	45.1	720.5	51.7	771.3	20
21	.3500	33.4	619.9	39.1	670.6	45.2	721.3	51.8	772.2	21
22	.3667	33.5	620.8	39.2	671.4	45.3	722.2	51.9	773.0	22
23	.3833	33.6	621.6	39.3	672.3	45.4	723.1	52.0	773.9	23
24	.4000	33.7	622.5	39.4	673.1	45.5	723.9	52.1	774.7	24
25	.4167	33.8	623.3	39.5	674.0	45.6	724.7	52.3	775.6	25
26	.4333	33.9	624.2	39.6	674.8	45.8	725.6	52.4	776.4	26
27	.4500	34.0	625.0	39.7	675.7	45.9	726.5	52.5	777.3	27
28	.4667	34.1	625.9	39.8	676.5	46.0	727.3	52.6	778.1	28
29	.4833	34.2	626.7	39.9	677.4	46.1	728.1	52.7	778.9	29
30	.5000	34.3	627.6	40.0	678.2	46.2	729.0	52.8	779.8	30
31	.5167	34.4	628.4	40.1	679.0	46.3	729.8	52.9	780.6	31
32	.5333	34.5	629.2	40.2	679.9	46.4	730.7	53.1	781.5	32
33	.5500	34.5	630.1	40.3	680.7	46.5	731.5	53.2	782.3	33
34	.5667	34.6	630.9	40.4	681.6	46.6	732.4	53.3	783.2	34
35	.5833	34.7	631.8	40.5	682.4	46.7	733.2	53.4	784.0	35
36	.6000	34.8	632.6	40.6	683.3	46.8	734.0	53.5	784.9	36
37	.6167	34.9	633.5	40.7	684.1	46.9	734.9	53.6	785.7	37
38	.6333	35.0	634.3	40.8	685.0	47.0	735.7	53.7	786.6	38
39	.6500	35.1	635.1	40.9	685.8	47.2	736.6	53.9	787.4	39
40	.6667	35.2	636.0	41.0	686.6	47.3	737.4	54.0	788.3	40
41	.6833	35.3	636.8	41.1	687.5	47.4	738.3	54.1	789.1	41
42	.7000	35.4	637.7	41.2	688.3	47.5	739.1	54.2	790.0	42
43	.7167	35.5	638.5	41.3	689.2	47.6	740.0	54.3	790.8	43
44	.7333	35.6	639.4	41.4	690.0	47.7	740.8	54.4	791.7	44
45	.7500	35.7	640.2	41.5	690.9	47.8	741.7	54.6	792.5	45
46	.7667	35.8	641.1	41.6	691.7	47.9	742.5	54.7	793.4	46
47	.7833	35.8	641.9	41.7	692.5	48.0	743.4	54.8	794.2	47
48	.8000	35.9	642.7	41.8	693.4	48.1	744.2	54.9	795.1	48
49	.8167	36.0	643.6	41.9	694.2	48.2	745.1	55.0	795.9	49
50	.8333	36.1	644.4	42.0	695.1	48.3	745.9	55.1	796.8	50
51	.8500	36.2	645.3	42.1	695.9	48.5	746.7	55.3	797.6	51
52	.8667	36.3	646.1	42.2	696.8	48.6	747.6	55.4	798.5	52
53	.8833	36.4	647.0	42.3	697.6	48.7	748.4	55.5	799.3	53
54	.9000	36.5	647.8	42.4	698.5	48.8	749.3	55.6	800.2	54
55	.9167	36.6	648.6	42.5	699.3	48.9	750.1	55.7	801.0	55
56	.9333	36.7	649.5	42.6	700.1	49.0	751.0	55.8	801.9	56
57	.9500	36.8	650.3	42.7	701.0	49.1	751.8	56.0	802.7	57
58	.9667	36.9	651.2	42.8	701.8	49.2	752.7	56.1	803.6	58
59	.9833	37.0	652.0	42.9	702.7	49.3	753.5	56.2	804.4	59

Use 100′ Chords up to 8° Curves
Use 50′ Chords up to 16° Curves
Use 25′ Chords up to 32° Curves
Use 10′ Chords above 32° Curves

Minutes	Dec. of Degree	16°		17°		18°		19°		Minutes
		Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	
0	.0000	56.3	805.3	63.6	856.4	71.4	907.5	79.7	958.9	0
1	.0167	56.4	806.2	63.8	857.2	71.6	908.4	79.8	959.7	1
2	.0333	56.5	807.0	63.9	858.1	71.7	909.2	79.9	960.6	2
3	.0500	56.7	807.8	64.0	858.9	71.8	910.1	80.1	961.4	3
4	.0667	56.8	808.6	64.2	859.8	72.0	910.9	80.2	962.3	4
5	.0833	56.9	809.5	64.3	860.6	72.1	911.8	80.4	963.2	5
6	.1000	57.0	810.4	64.4	861.5	72.2	912.7	80.5	964.0	6
7	.1167	57.1	811.2	64.5	862.3	72.4	913.5	80.7	964.9	7
8	.1333	57.3	812.1	64.7	863.2	72.5	914.4	80.8	965.7	8
9	.1500	57.4	812.9	64.8	864.0	72.6	915.2	80.9	966.6	9
10	.1667	57.5	813.8	64.9	864.9	72.8	916.1	81.1	967.4	10
11	.1833	57.6	814.6	65.0	865.7	72.9	916.9	81.2	968.3	11
12	.2000	57.7	815.5	65.2	866.6	73.0	917.8	81.4	969.2	12
13	.2167	57.9	816.3	65.3	867.4	73.2	918.6	81.5	970.0	13
14	.2333	58.0	817.2	65.4	868.3	73.3	919.5	81.7	970.9	14
15	.2500	58.1	818.0	65.6	869.1	73.4	920.3	81.8	971.7	15
16	.2667	58.2	818.9	65.7	870.0	73.6	921.2	81.9	972.6	16
17	.2833	58.3	819.7	65.8	870.8	73.7	922.0	82.1	973.4	17
18	.3000	58.5	820.6	65.9	871.7	73.9	922.9	82.2	974.3	18
19	.3167	58.6	821.4	66.1	872.5	74.0	923.8	82.4	975.1	19
20	.3333	58.7	822.3	66.2	873.4	74.1	924.6	82.5	976.0	20
21	.3500	58.8	823.1	66.3	874.2	74.3	925.5	82.7	976.9	21
22	.3667	58.9	824.0	66.4	875.1	74.4	926.3	82.8	977.7	22
23	.3833	59.1	824.8	66.6	875.9	74.5	927.2	82.9	978.6	23
24	.4000	59.2	825.7	66.7	876.8	74.7	928.1	83.1	979.4	24
25	.4167	59.3	826.5	66.8	877.6	74.8	928.9	83.2	980.3	25
26	.4333	59.4	827.4	67.0	878.5	74.9	929.8	83.4	981.2	26
27	.4500	59.6	828.2	67.1	879.3	75.1	930.6	83.5	982.0	27
28	.4667	59.7	829.1	67.2	880.2	75.2	931.5	83.7	982.9	28
29	.4833	59.8	829.9	67.3	881.0	75.4	932.3	83.8	983.7	29
30	.5000	59.9	830.8	67.5	881.9	75.5	933.2	84.0	984.6	30
31	.5167	60.0	831.6	67.6	882.7	75.6	934.0	84.1	985.4	31
32	.5333	60.2	832.5	67.7	883.6	75.8	934.9	84.3	986.3	32
33	.5500	60.3	833.3	67.9	884.5	75.9	935.7	84.4	987.2	33
34	.5667	60.4	834.2	68.0	885.3	76.1	936.6	84.6	988.0	34
35	.5833	60.5	835.1	68.1	886.2	76.2	937.5	84.7	988.9	35
36	.6000	60.7	835.9	68.2	887.0	76.3	938.3	84.8	989.7	36
37	.6167	60.8	836.8	68.4	887.9	76.5	939.2	85.0	990.6	37
38	.6333	60.9	837.6	68.5	888.7	76.6	940.0	85.1	991.5	38
39	.6500	61.0	838.5	68.6	889.6	76.7	940.9	85.3	992.3	39
40	.6667	61.1	839.3	68.8	890.4	76.9	941.7	85.4	993.2	40
41	.6833	61.3	840.2	68.9	891.3	77.0	942.6	85.6	994.0	41
42	.7000	61.4	841.0	69.0	892.2	77.1	943.5	85.7	994.9	42
43	.7167	61.5	841.9	69.2	893.0	77.3	944.3	85.9	995.8	43
44	.7333	61.6	842.7	69.3	893.9	77.4	945.2	86.0	996.6	44
45	.7500	61.8	843.6	69.4	894.7	77.6	946.0	86.2	997.5	45
46	.7667	61.9	844.4	69.6	895.6	77.7	946.9	86.3	998.3	46
47	.7833	62.0	845.3	69.7	896.4	77.8	947.7	86.5	999.2	47
48	.8000	62.1	846.1	69.8	897.3	78.0	948.6	86.6	1000.0	48
49	.8167	62.3	847.0	70.0	898.1	78.1	949.4	86.8	1000.9	49
50	.8333	62.4	847.8	70.1	899.0	78.3	950.3	86.9	1001.8	50
51	.8500	62.5	848.7	70.2	899.8	78.4	951.1	87.1	1002.6	51
52	.8667	62.6	849.5	70.4	900.7	78.5	952.0	87.2	1003.5	52
53	.8833	62.8	850.4	70.5	901.5	78.7	952.9	87.4	1004.3	53
54	.9000	62.9	851.2	70.6	902.4	78.8	953.7	87.5	1005.2	54
55	.9167	63.0	852.1	70.8	903.3	79.0	954.6	87.7	1006.0	55
56	.9333	63.1	852.9	70.9	904.1	79.1	955.4	87.8	1006.9	56
57	.9500	63.3	853.8	71.0	905.0	79.2	956.3	88.0	1007.7	57
58	.9667	63.4	854.7	71.2	905.8	79.4	957.2	88.1	1008.6	58
59	.9833	63.5	855.5	71.3	906.7	79.5	958.0	88.2	1009.5	59

Use 100′ Chords up to 8° Curves Use 25′ Chords up to 32°
Use 50′ Chords up to 16° Curves Use 10′ Chords above 32°

Minutes	Dec. of Degree	20° Ext.	20° Tan.	21° Ext.	21° Tan.	22° Ext.	22° Tan.	23° Ext.	23° Tan.	Minutes
0	.0000	88.4	1010.4	97.6	1062.0	107.2	1113.8	117.4	1165.8	0
1	.0167	88.5	1011.2	97.7	1062.8	107.4	1114.6	117.6	1166.6	1
2	.0333	88.7	1012.1	97.9	1063.7	107.6	1115.5	117.7	1167.5	2
3	.0500	88.8	1012.9	98.1	1064.5	107.7	1116.4	117.9	1168.3	3
4	.0667	89.0	1013.8	98.2	1065.4	107.9	1117.3	118.1	1169.2	4
5	.0833	89.1	1014.6	98.4	1066.3	108.0	1118.1	118.3	1170.1	5
6	.1000	89.3	1015.5	98.5	1067.2	108.2	1119.0	118.4	1171.0	6
7	.1167	89.4	1016.3	98.7	1068.0	108.4	1119.8	118.6	1171.8	7
8	.1333	89.6	1017.2	98.8	1068.9	108.6	1120.7	118.8	1172.7	8
9	.1500	89.7	1018.1	99.0	1069.7	108.7	1121.5	118.9	1173.5	9
10	.1667	89.9	1019.0	99.2	1070.6	108.9	1122.4	119.1	1174.4	10
11	.1833	90.0	1019.8	99.3	1071.5	109.0	1123.3	119.3	1175.3	11
12	.2000	90.2	1020.7	99.5	1072.4	109.2	1124.2	119.5	1176.2	12
13	.2167	90.3	1021.5	99.6	1073.2	109.4	1125.0	119.7	1177.0	13
14	.2333	90.5	1022.4	99.8	1074.1	109.6	1125.9	119.8	1177.9	14
15	.2500	90.6	1023.2	99.9	1074.9	109.7	1126.7	120.0	1178.8	15
16	.2667	90.8	1024.1	100.1	1075.8	109.9	1127.6	120.2	1179.7	16
17	.2833	90.9	1024.9	100.2	1076.6	110.0	1128.5	120.4	1180.5	17
18	.3000	91.1	1025.8	100.4	1077.5	110.2	1129.4	120.5	1181.4	18
19	.3167	91.2	1026.7	100.5	1078.4	110.4	1130.2	120.7	1182.2	19
20	.3333	91.4	1027.6	100.7	1079.3	110.6	1131.1	120.9	1183.1	20
21	.3500	91.6	1028.4	100.9	1080.1	110.7	1131.9	121.0	1184.0	21
22	.3667	91.7	1029.3	101.1	1081.0	110.9	1132.8	121.2	1184.9	22
23	.3833	91.9	1030.1	101.2	1081.8	111.0	1133.7	121.4	1185.7	23
24	.4000	92.0	1031.0	101.4	1082.7	111.2	1134.6	121.6	1186.6	24
25	.4167	92.2	1031.8	101.5	1083.5	111.4	1135.4	121.7	1187.5	25
26	.4333	92.3	1032.7	101.7	1084.4	111.6	1136.3	121.9	1188.4	26
27	.4500	92.5	1033.5	101.8	1085.3	111.7	1137.1	122.1	1189.2	27
28	.4667	92.6	1034.4	102.0	1086.2	111.9	1138.0	122.3	1190.1	28
29	.4833	92.8	1035.2	102.1	1087.0	112.1	1138.8	122.4	1190.9	29
30	.5000	92.9	1036.1	102.3	1087.9	112.3	1139.7	122.6	1191.8	30
31	.5167	93.1	1037.0	102.5	1088.7	112.4	1140.6	122.8	1192.7	31
32	.5333	93.2	1037.9	102.7	1089.6	112.6	1141.5	123.0	1193.6	32
33	.5500	93.4	1038.7	102.8	1090.4	112.7	1142.3	123.2	1194.4	33
34	.5667	93.5	1039.6	103.0	1091.3	112.9	1143.2	123.3	1195.3	34
35	.5833	93.7	1040.4	103.1	1092.2	113.1	1144.0	123.5	1196.2	35
36	.6000	93.9	1041.3	103.3	1093.1	113.3	1144.9	123.7	1197.1	36
37	.6167	94.0	1042.1	103.4	1093.9	113.4	1145.8	123.9	1197.9	37
38	.6333	94.2	1043.0	103.6	1094.8	113.6	1146.7	124.1	1198.8	38
39	.6500	94.3	1043.9	103.8	1095.6	113.7	1147.5	124.3	1199.6	39
40	.6667	94.5	1044.8	104.0	1096.5	113.9	1148.4	124.4	1200.5	40
41	.6833	94.6	1045.6	104.1	1097.4	114.1	1149.2	124.6	1201.4	41
42	.7000	94.8	1046.5	104.3	1098.3	114.3	1150.1	124.8	1202.3	42
43	.7167	94.9	1047.3	104.4	1099.1	114.4	1151.0	124.9	1203.1	43
44	.7333	95.1	1048.2	104.6	1100.0	114.6	1151.9	125.1	1204.0	44
45	.7500	95.2	1049.0	104.7	1100.8	114.8	1152.7	125.3	1204.9	45
46	.7667	95.4	1049.9	104.9	1101.7	115.0	1153.6	125.5	1205.8	46
47	.7833	95.6	1050.8	105.1	1102.5	115.2	1154.5	125.7	1206.7	47
48	.8000	95.7	1051.7	105.3	1103.4	115.3	1155.4	125.8	1207.5	48
49	.8167	95.9	1052.5	105.4	1104.3	115.5	1156.2	126.0	1208.3	49
50	.8333	96.0	1053.4	105.6	1105.2	115.7	1157.1	126.2	1209.2	50
51	.8500	96.2	1054.2	105.7	1106.0	115.8	1157.9	126.4	1210.1	51
52	.8667	96.3	1055.1	105.9	1106.9	116.0	1158.8	126.6	1211.0	52
53	.8833	96.5	1055.9	106.1	1107.8	116.1	1159.7	126.7	1211.8	53
54	.9000	96.7	1056.8	106.3	1108.6	116.3	1160.6	126.9	1212.7	54
55	.9167	96.8	1057.7	106.4	1109.4	116.5	1161.4	127.1	1213.6	55
56	.9333	97.0	1058.6	106.6	1110.3	116.7	1162.3	127.3	1214.5	56
57	.9500	97.1	1059.4	106.7	1111.2	116.8	1163.1	127.5	1215.3	57
58	.9667	97.3	1060.3	106.9	1112.1	117.0	1164.0	127.6	1216.2	58
59	.9833	97.4	1061.1	107.0	1112.9	117.2	1164.9	127.8	1217.1	59

Use 100′ Chords up to 8° Curves   Use 25′ Chords up to 32° Curves
Use 50′ Chords up to 16° Curves   Use 10′ Chords above 32° Curves

Minutes	Dec. of Degree	24°		25°		26°		27°		Minutes
		Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	
0	.0000	128.0	1218.0	139.1	1270.3	150.7	1322.9	162.8	1375.6	0
1	.0167	128.2	1218.8	139.3	1271.1	150.9	1323.7	163.0	1376.5	1
2	.0333	128.4	1219.7	139.5	1272.0	151.1	1324.6	163.2	1377.4	2
3	.0500	128.5	1220.5	139.7	1272.9	151.3	1325.5	163.5	1378.3	3
4	.0667	128.7	1221.4	139.9	1273.8	151.5	1326.4	163.7	1379.2	4
5	.0833	128.9	1222.3	140.1	1274.6	151.7	1327.3	163.9	1380.0	5
6	.1000	129.1	1223.2	140.3	1275.5	151.9	1328.1	164.1	1380.9	6
7	.1167	129.3	1224.0	140.4	1276.4	152.1	1329.0	164.3	1381.8	7
8	.1333	129.5	1224.9	140.6	1277.3	152.3	1329.9	164.5	1382.7	8
9	.1500	129.7	1225.8	140.8	1278.2	152.5	1330.7	164.7	1383.6	9
10	.1667	129.8	1226.7	141.0	1279.1	152.7	1331.6	164.9	1384.5	10
11	.1833	130.0	1227.5	141.2	1279.9	152.9	1332.5	165.1	1385.3	11
12	.2000	130.2	1228.4	141.4	1280.8	153.1	1333.4	165.3	1386.2	12
13	.2167	130.4	1229.3	141.6	1281.6	153.3	1334.3	165.5	1387.1	13
14	.2333	130.6	1230.2	141.8	1282.5	153.5	1335.2	165.7	1388.0	14
15	.2500	130.7	1231.0	142.0	1283.4	153.7	1336.0	165.9	1388.9	15
16	.2667	130.9	1231.9	142.2	1284.3	153.9	1336.9	166.1	1389.8	16
17	.2833	131.1	1232.7	142.3	1285.2	154.1	1337.8	166.3	1390.6	17
18	.3000	131.3	1233.6	142.5	1286.1	154.3	1338.7	166.5	1391.5	18
19	.3167	131.5	1234.5	142.7	1286.9	154.5	1339.5	166.7	1392.4	19
20	.3333	131.7	1235.4	142.9	1287.8	154.7	1340.4	167.0	1393.3	20
21	.3500	131.9	1236.2	143.1	1288.7	154.9	1341.3	167.2	1394.1	21
22	.3667	132.0	1237.1	143.3	1289.6	155.1	1342.2	167.4	1395.0	22
23	.3833	132.2	1238.0	143.5	1290.4	155.3	1343.0	167.6	1395.9	23
24	.4000	132.4	1238.9	143.7	1291.3	155.5	1343.9	167.8	1396.8	24
25	.4167	132.6	1239.7	143.9	1292.2	155.7	1344.8	168.0	1397.7	25
26	.4333	132.8	1240.6	144.1	1293.1	155.9	1345.7	168.2	1398.6	26
27	.4500	133.0	1241.5	144.3	1293.9	156.1	1346.5	168.4	1399.4	27
28	.4667	133.1	1242.4	144.5	1294.8	156.3	1347.4	168.6	1400.3	28
29	.4833	133.3	1243.2	144.7	1295.7	156.5	1348.3	168.9	1401.2	29
30	.5000	133.5	1244.1	144.9	1296.6	156.7	1349.2	169.1	1402.1	30
31	.5167	133.7	1244.9	145.1	1297.4	156.9	1350.1	169.3	1403.0	31
32	.5333	133.9	1245.8	145.3	1298.3	157.1	1351.0	169.5	1403.9	32
33	.5500	134.0	1246.7	145.5	1299.2	157.3	1351.8	169.7	1404.7	33
34	.5667	134.2	1247.6	145.6	1300.1	157.5	1352.7	169.9	1405.6	34
35	.5833	134.4	1248.4	145.8	1300.9	157.7	1353.6	170.1	1406.5	35
36	.6000	134.6	1249.3	146.0	1301.8	157.9	1354.5	170.3	1407.4	36
37	.6167	134.9	1250.2	146.2	1302.7	158.1	1355.3	170.5	1408.3	37
38	.6333	135.0	1251.1	146.4	1303.6	158.3	1356.2	170.8	1409.2	38
39	.6500	135.2	1251.9	146.6	1304.4	158.5	1357.1	171.0	1410.0	39
40	.6667	135.4	1252.8	146.8	1305.3	158.7	1358.0	171.2	1410.9	40
41	.6833	135.6	1253.7	147.0	1306.2	158.9	1358.9	171.4	1411.8	41
42	.7000	135.7	1254.6	147.2	1307.1	159.1	1359.8	171.6	1412.7	42
43	.7167	135.9	1255.4	147.4	1307.9	159.3	1360.6	171.8	1413.6	43
44	.7333	136.1	1256.3	147.6	1308.8	159.5	1361.5	172.0	1414.5	44
45	.7500	136.3	1257.2	147.8	1309.7	159.7	1362.4	172.2	1415.4	45
46	.7667	136.5	1258.1	148.0	1310.6	160.0	1363.3	172.5	1416.3	46
47	.7833	136.7	1258.9	148.2	1311.5	160.2	1364.2	172.7	1417.1	47
48	.8000	136.9	1259.8	148.4	1312.4	160.4	1365.1	172.9	1418.0	48
49	.8167	137.1	1260.7	148.6	1313.2	160.6	1365.9	173.1	1418.9	49
50	.8333	137.2	1261.5	148.8	1314.1	160.8	1366.8	173.3	1419.8	50
51	.8500	137.4	1262.4	149.0	1315.0	161.0	1367.7	173.5	1420.7	51
52	.8667	137.6	1263.3	149.2	1315.9	161.2	1368.6	173.7	1421.6	52
53	.8833	137.8	1264.1	149.4	1316.7	161.4	1369.5	173.9	1422.4	53
54	.9000	138.0	1265.0	149.5	1317.6	161.6	1370.4	174.1	1423.3	54
55	.9167	138.2	1265.9	149.7	1318.5	161.8	1371.2	174.4	1424.2	55
56	.9333	138.4	1266.8	149.9	1319.4	162.0	1372.1	174.6	1425.1	56
57	.9500	138.6	1267.6	150.1	1320.3	162.2	1373.0	174.8	1426.0	57
58	.9667	138.7	1268.5	150.3	1321.1	162.4	1373.9	175.0	1426.9	58
59	.9833	138.9	1269.4	150.5	1322.0	162.6	1374.7	175.2	1427.7	59

Use 100′ Chords up to 8° Curves Use 25′ Chords up to 32° Curves
Use 50′ Chords up to 16° Curves Use 10′ Chords above 32° Curves

Minutes	Dec. of Degree	28° Ext.	28° Tan.	29° Ext.	29° Tan.	30° Ext.	30° Tan.	31° Ext.	31° Tan.	Minutes
0	.0000	175.4	1428.6	188.5	1481.9	202.1	1535.3	216.3	1589.0	0
1	.0167	175.6	1429.5	188.7	1482.8	202.3	1536.2	216.5	1589.9	1
2	.0333	175.8	1430.4	189.0	1483.7	202.6	1537.1	216.8	1590.8	2
3	.0500	176.0	1431.3	189.2	1484.5	202.8	1538.0	217.0	1591.7	3
4	.0667	176.3	1432.2	189.4	1485.4	203.1	1538.9	217.2	1592.6	4
5	.0833	176.5	1433.1	189.6	1486.3	203.3	1539.8	217.4	1593.5	5
6	.1000	176.7	1434.0	189.9	1487.2	203.5	1540.7	217.7	1594.4	6
7	.1167	176.9	1434.8	190.1	1488.1	203.7	1541.6	217.9	1595.3	7
8	.1333	177.1	1435.7	190.3	1489.0	204.0	1542.5	218.2	1596.2	8
9	.1500	177.3	1436.6	190.5	1489.9	204.2	1543.4	218.4	1597.1	9
10	.1667	177.6	1437.5	190.8	1490.8	204.5	1544.3	218.7	1598.0	10
11	.1833	177.8	1438.4	191.0	1491.7	204.7	1545.2	218.9	1598.9	11
12	.2000	178.0	1439.3	191.2	1492.6	204.9	1546.0	219.2	1599.8	12
13	.2167	178.2	1440.2	191.5	1493.4	205.1	1546.9	219.4	1600.7	13
14	.2333	178.4	1441.1	191.7	1494.3	205.4	1547.8	219.6	1601.6	14
15	.2500	178.6	1441.9	191.9	1495.2	205.6	1548.7	219.8	1602.5	15
16	.2667	178.9	1442.8	192.1	1496.1	205.9	1549.6	220.1	1603.4	16
17	.2833	179.1	1443.7	192.3	1497.0	206.1	1550.5	220.3	1604.3	17
18	.3000	179.3	1444.6	192.5	1497.9	206.3	1551.4	220.6	1605.2	18
19	.3167	179.5	1445.5	192.7	1498.8	206.5	1552.3	220.8	1606.1	19
20	.3333	179.7	1446.4	193.0	1499.7	206.8	1553.2	221.1	1607.0	20
21	.3500	179.9	1447.3	193.2	1500.6	207.0	1554.1	221.3	1607.9	21
22	.3667	180.2	1448.2	193.5	1501.5	207.3	1555.0	221.6	1608.8	22
23	.3833	180.4	1449.0	193.7	1502.3	207.5	1555.9	221.8	1609.7	23
24	.4000	180.6	1449.9	193.9	1503.2	207.7	1556.8	222.1	1610.6	24
25	.4167	180.8	1450.8	194.1	1504.1	207.9	1557.7	222.3	1611.5	25
26	.4333	181.0	1451.7	194.4	1505.0	208.2	1558.6	222.6	1612.4	26
27	.4500	181.2	1452.6	194.6	1505.9	208.4	1559.5	222.8	1613.3	27
28	.4667	181.5	1453.5	194.8	1506.8	208.7	1560.4	223.0	1614.2	28
29	.4833	181.7	1454.3	195.0	1507.7	208.9	1561.3	223.2	1615.1	29
30	.5000	181.9	1455.2	195.3	1508.6	209.1	1562.2	223.5	1616.0	30
31	.5167	182.1	1456.1	195.5	1509.5	209.3	1563.1	223.7	1616.9	31
32	.5333	182.3	1457.0	195.7	1510.4	209.6	1564.0	224.0	1617.8	32
33	.5500	182.5	1457.9	195.9	1511.2	209.8	1564.9	224.2	1618.7	33
34	.5667	182.8	1458.8	196.2	1512.1	210.1	1565.7	224.5	1619.6	34
35	.5833	183.0	1459.7	196.4	1513.0	210.3	1566.6	224.7	1620.5	35
36	.6000	183.2	1460.6	196.7	1513.9	210.5	1567.5	225.0	1621.4	36
37	.6167	183.4	1461.4	196.9	1514.8	210.7	1568.4	225.2	1622.3	37
38	.6333	183.6	1462.3	197.1	1515.7	211.0	1569.3	225.5	1623.2	38
39	.6500	183.8	1463.2	197.3	1516.6	211.2	1570.2	225.7	1624.1	39
40	.6667	184.1	1464.1	197.6	1517.5	211.5	1571.1	226.0	1625.0	40
41	.6833	184.3	1465.0	197.8	1518.4	211.7	1572.0	226.2	1625.9	41
42	.7000	184.5	1465.9	198.0	1519.3	212.0	1572.9	226.5	1626.8	42
43	.7167	184.7	1466.8	198.2	1520.1	212.2	1573.8	226.7	1627.7	43
44	.7333	185.0	1467.7	198.5	1521.0	212.4	1574.7	227.0	1628.6	44
45	.7500	185.2	1468.6	198.7	1521.9	212.6	1575.6	227.2	1629.5	45
46	.7667	185.4	1469.5	198.9	1522.8	212.9	1576.5	227.5	1630.5	46
47	.7833	185.6	1470.3	199.1	1523.7	213.1	1577.4	227.7	1631.4	47
48	.8000	185.9	1471.2	199.4	1524.6	213.4	1578.3	228.0	1632.3	48
49	.8167	186.1	1472.1	199.6	1525.5	213.6	1579.2	228.2	1633.2	49
50	.8333	186.3	1473.0	199.8	1526.4	213.9	1580.1	228.4	1634.1	50
51	.8500	186.5	1473.9	200.0	1527.3	214.1	1581.0	228.6	1635.0	51
52	.8667	186.8	1474.8	200.3	1528.2	214.4	1581.9	228.9	1635.9	52
53	.8833	187.0	1475.7	200.5	1529.1	214.6	1582.8	229.1	1636.8	53
54	.9000	187.2	1476.6	200.8	1530.0	214.8	1583.7	229.4	1637.7	54
55	.9167	187.4	1477.4	201.0	1530.9	215.0	1584.6	229.6	1638.6	55
56	.9333	187.6	1478.3	201.2	1531.7	215.3	1585.5	229.9	1639.5	56
57	.9500	187.8	1479.2	201.4	1532.6	215.5	1586.3	230.1	1640.4	57
58	.9667	188.1	1480.1	201.7	1533.5	215.8	1587.2	230.4	1641.3	58
59	.9833	188.3	1481.0	201.9	1534.4	216.0	1588.1	230.6	1642.2	59

Use 100′ Chords up to 8° Curves
Use 50′ Chords up to 16° Curves
Use 25′ Chords up to 32° Curves
Use 10′ Chords above 32° Curves

Minutes	Dec. of Degree	32° Ext.	32° Tan.	33° Ext.	33° Tan.	34° Ext.	34° Tan.	35° Ext.	35° Tan.	Minutes
0	.0000	230.9	1643.1	246.1	1697.3	261.8	1751.8	278.1	1806.7	0
1	.0167	231.1	1644.0	246.3	1698.2	262.0	1752.7	278.4	1807.6	1
2	.0333	231.4	1644.9	246.6	1699.1	262.3	1753.7	278.6	1808.5	2
3	.0500	231.6	1645.8	246.8	1700.0	262.6	1754.6	278.9	1809.4	3
4	.0667	231.9	1646.7	247.1	1700.9	262.9	1755.5	279.2	1810.3	4
5	.0833	232.1	1647.6	247.4	1701.8	263.1	1756.4	279.4	1811.2	5
6	.1000	232.4	1648.5	247.7	1702.7	263.4	1757.3	279.7	1812.2	6
7	.1167	232.6	1649.4	247.9	1703.6	263.7	1758.2	280.0	1813.1	7
8	.1333	232.9	1650.3	248.2	1704.5	264.0	1759.1	280.3	1814.0	8
9	.1500	233.1	1651.2	248.4	1705.4	264.2	1760.0	280.6	1814.9	9
10	.1667	233.4	1652.1	248.7	1706.4	264.5	1761.0	280.8	1815.8	10
11	.1833	233.6	1653.0	248.9	1707.3	264.7	1761.9	281.1	1816.7	11
12	.2000	233.9	1653.9	249.2	1708.2	265.0	1762.8	281.4	1817.7	12
13	.2167	234.1	1654.8	249.4	1709.1	265.3	1763.7	281.6	1818.6	13
14	.2333	234.4	1655.7	249.7	1710.0	265.6	1764.6	281.9	1819.5	14
15	.2500	234.6	1656.6	249.9	1710.9	265.9	1765.5	282.2	1820.4	15
16	.2667	234.9	1657.5	250.2	1711.8	266.1	1766.4	282.5	1821.3	16
17	.2833	235.1	1658.4	250.5	1712.7	266.4	1767.3	282.7	1822.2	17
18	.3000	235.4	1659.3	250.8	1713.6	266.7	1768.3	283.0	1823.2	18
19	.3167	235.6	1660.2	251.0	1714.5	266.9	1769.2	283.3	1824.1	19
20	.3333	235.9	1661.1	251.3	1715.5	267.2	1770.1	283.6	1825.0	20
21	.3500	236.1	1662.0	251.5	1716.4	267.4	1771.0	283.9	1825.9	21
22	.3667	236.4	1662.9	251.8	1717.3	267.7	1771.9	284.2	1826.8	22
23	.3833	236.6	1663.8	252.0	1718.2	268.0	1772.8	284.4	1827.7	23
24	.4000	236.9	1664.7	252.3	1719.1	268.3	1773.7	284.7	1828.7	24
25	.4167	237.1	1665.6	252.6	1720.0	268.6	1774.6	285.0	1829.6	25
26	.4333	237.4	1666.5	252.9	1720.9	268.8	1775.6	285.3	1830.5	26
27	.4500	237.6	1667.4	253.1	1721.8	269.1	1776.5	285.6	1831.4	27
28	.4667	237.9	1668.3	253.4	1722.7	269.3	1777.4	285.9	1832.3	28
29	.4833	238.1	1669.2	253.6	1723.6	269.6	1778.3	286.1	1833.2	29
30	.5000	238.4	1670.1	253.9	1724.6	269.9	1779.2	286.4	1834.2	30
31	.5167	238.7	1671.0	254.1	1725.5	270.1	1780.1	286.7	1835.1	31
32	.5333	239.0	1671.9	254.4	1726.4	270.4	1781.0	287.0	1836.0	32
33	.5500	239.2	1672.8	254.7	1727.3	270.7	1781.9	287.2	1836.9	33
34	.5667	239.5	1673.7	255.0	1728.2	271.0	1782.9	287.5	1837.8	34
35	.5833	239.7	1674.6	255.2	1729.1	271.2	1783.8	287.8	1838.7	35
36	.6000	240.0	1675.5	255.5	1730.0	271.5	1784.7	288.1	1839.7	36
37	.6167	240.2	1676.4	255.7	1730.9	271.7	1785.6	288.4	1840.6	37
38	.6333	240.5	1677.4	256.0	1731.8	272.0	1786.5	288.7	1841.5	38
39	.6500	240.7	1678.3	256.2	1732.7	272.3	1787.4	289.0	1842.4	39
40	.6667	241.0	1679.2	256.5	1733.6	272.6	1788.4	289.2	1843.4	40
41	.6833	241.2	1680.1	256.8	1734.5	272.9	1789.3	289.5	1844.3	41
42	.7000	241.5	1681.0	257.1	1735.5	273.1	1790.2	289.8	1845.2	42
43	.7167	241.7	1681.9	257.3	1736.4	273.4	1791.1	290.1	1846.1	43
44	.7333	242.0	1682.8	257.6	1737.3	273.7	1792.0	290.4	1847.1	44
45	.7500	242.2	1683.7	257.8	1738.2	274.0	1792.9	290.6	1848.0	45
46	.7667	242.5	1684.6	258.1	1739.1	274.2	1793.9	290.9	1848.9	46
47	.7833	242.7	1685.5	258.3	1740.0	274.5	1794.8	291.2	1849.8	47
48	.8000	243.0	1686.4	258.6	1740.9	274.8	1795.7	291.5	1850.7	48
49	.8167	243.2	1687.3	258.9	1741.8	275.0	1796.6	291.8	1851.6	49
50	.8333	243.5	1688.2	259.2	1742.7	275.3	1797.5	292.0	1852.6	50
51	.8500	243.8	1689.1	259.4	1743.6	275.6	1798.4	292.3	1853.5	51
52	.8667	244.1	1690.0	259.7	1744.6	275.9	1799.3	292.6	1854.4	52
53	.8833	244.3	1690.9	259.9	1745.5	276.1	1800.2	292.9	1855.3	53
54	.9000	244.6	1691.8	260.2	1746.4	276.4	1801.2	293.2	1856.3	54
55	.9167	244.8	1692.7	260.5	1747.3	276.7	1802.1	293.4	1857.2	55
56	.9333	245.1	1693.7	260.8	1748.2	277.0	1803.0	293.7	1858.1	56
57	.9500	245.3	1694.6	261.0	1749.1	277.3	1803.9	294.0	1859.0	57
58	.9667	245.6	1695.5	261.3	1750.0	277.5	1804.8	294.3	1859.9	58
59	.9833	245.8	1696.4	261.5	1750.9	277.8	1805.7	294.6	1860.8	59

Use 100′ Chords up to 8° Curves **Use 25′ Chords up to 32° Curves**
Use 50′ Chords up to 16° Curves **Use 10′ Chords above 32° Curves**

Minutes	Dec. of Degree	36° Ext.	36° Tan.	37° Ext.	37° Tan.	38° Ext.	38° Tan.	39° Ext.	39° Tan.	Minutes
0	.0000	294.9	1861.8	312.3	1917.3	330.2	1973.0	348.7	2029.1	0
1	.0167	295.2	1862.7	312.5	1918.2	330.5	1973.9	349.0	2030.0	1
2	.0333	295.4	1863.6	312.8	1919.1	330.8	1974.9	349.3	2031.0	2
3	.0500	295.7	1864.5	313.1	1920.0	331.1	1975.8	349.6	2031.9	3
4	.0667	296.0	1865.5	313.4	1921.0	331.4	1976.7	349.9	2032.9	4
5	.0833	296.3	1866.4	313.7	1921.9	331.7	1977.6	350.3	2033.8	5
6	.1000	296.6	1867.3	314.0	1922.8	332.0	1978.6	350.6	2034.7	6
7	.1167	296.9	1868.2	314.3	1923.7	332.3	1979.5	350.9	2035.6	7
8	.1333	297.2	1869.2	314.6	1924.7	332.6	1980.5	351.2	2036.6	8
9	.1500	297.5	1870.1	314.9	1925.6	332.9	1981.4	351.5	2037.5	9
10	.1667	297.7	1871.0	315.2	1926.5	333.2	1982.3	351.8	2038.5	10
11	.1833	298.0	1871.9	315.5	1927.4	333.5	1983.2	352.1	2039.4	11
12	.2000	298.3	1872.9	315.8	1928.4	333.8	1984.2	352.4	2040.4	12
13	.2167	298.6	1873.8	316.1	1929.3	334.2	1985.1	352.8	2041.3	13
14	.2333	298.9	1874.7	316.4	1930.2	334.5	1986.1	353.1	2042.3	14
15	.2500	299.2	1875.6	316.7	1931.1	334.8	1987.0	353.4	2043.2	15
16	.2667	299.5	1876.5	317.0	1932.1	335.1	1987.9	353.7	2044.1	16
17	.2833	299.7	1877.4	317.2	1933.0	335.4	1988.8	354.0	2045.0	17
18	.3000	300.0	1878.4	317.5	1933.9	335.7	1989.8	354.3	2046.0	18
19	.3167	300.3	1879.3	317.8	1934.8	336.0	1990.7	354.6	2046.9	19
20	.3333	300.6	1880.2	318.1	1935.8	336.3	1991.7	354.9	2047.9	20
21	.3500	300.9	1881.1	318.4	1936.7	336.6	1992.6	355.3	2048.8	21
22	.3667	301.2	1882.1	318.7	1937.6	336.9	1993.6	355.6	2049.8	22
23	.3833	301.5	1883.0	319.0	1938.5	337.2	1994.5	355.9	2050.7	23
24	.4000	301.8	1883.9	319.3	1939.5	337.5	1995.4	356.2	2051.7	24
25	.4167	302.0	1884.8	319.6	1940.4	337.8	1996.3	356.6	2052.6	25
26	.4333	302.3	1885.8	319.9	1941.3	338.1	1997.3	356.9	2053.5	26
27	.4500	302.6	1886.7	320.2	1942.2	338.4	1998.2	357.2	2054.4	27
28	.4667	302.9	1887.6	320.5	1943.2	338.7	1999.2	357.5	2055.4	28
29	.4833	303.2	1888.5	320.8	1944.1	339.1	2000.1	357.8	2056.3	29
30	.5000	303.5	1889.5	321.1	1945.0	339.4	2001.0	358.1	2057.3	30
31	.5167	303.8	1890.4	321.4	1945.9	339.7	2001.9	358.4	2058.2	31
32	.5333	304.1	1891.3	321.7	1946.9	340.0	2002.9	358.8	2059.2	32
33	.5500	304.3	1892.2	322.0	1947.8	340.3	2003.8	359.1	2060.1	33
34	.5667	304.6	1893.2	322.3	1948.8	340.6	2004.8	359.4	2061.1	34
35	.5833	304.9	1894.1	322.6	1949.7	340.9	2005.7	359.8	2062.0	35
36	.6000	305.2	1895.0	322.9	1950.6	341.2	2006.6	360.1	2063.0	36
37	.6167	305.5	1895.9	323.2	1951.5	341.5	2007.5	360.4	2063.9	37
38	.6333	305.8	1896.9	323.5	1952.5	341.8	2008.5	360.7	2064.8	38
39	.6500	306.1	1897.8	323.8	1953.4	342.1	2009.4	361.0	2065.7	39
40	.6667	306.4	1898.7	324.2	1954.4	342.4	2010.4	361.3	2066.7	40
41	.6833	306.7	1899.6	324.5	1955.3	342.8	2011.3	361.6	2067.6	41
42	.7000	307.0	1900.6	324.8	1956.2	343.1	2012.3	362.0	2068.6	42
43	.7167	307.2	1901.5	325.1	1957.1	343.4	2013.2	362.3	2069.5	43
44	.7333	307.5	1902.4	325.4	1958.1	343.7	2014.1	362.6	2070.5	44
45	.7500	307.8	1903.3	325.7	1959.0	344.0	2015.0	363.0	2071.4	45
46	.7667	308.1	1904.3	326.0	1960.0	344.3	2016.0	363.3	2072.4	46
47	.7833	308.4	1905.2	326.3	1960.9	344.6	2016.9	363.6	2073.3	47
48	.8000	308.7	1906.1	326.6	1961.8	344.9	2017.9	363.9	2074.2	48
49	.8167	309.0	1907.0	326.9	1962.7	345.3	2018.8	364.2	2075.1	49
50	.8333	309.3	1908.0	327.2	1963.7	345.6	2019.7	364.5	2076.1	50
51	.8500	309.6	1908.9	327.5	1964.6	345.9	2020.6	364.9	2077.0	51
52	.8667	309.9	1909.8	327.8	1965.5	346.2	2021.6	365.2	2078.0	52
53	.8833	310.2	1910.7	328.1	1966.4	346.5	2022.5	365.5	2078.9	53
54	.9000	310.5	1911.7	328.4	1967.4	346.8	2023.5	365.8	2079.9	54
55	.9167	310.8	1912.6	328.7	1968.3	347.1	2024.4	366.2	2080.8	55
56	.9333	311.1	1913.5	329.0	1969.3	347.4	2025.4	366.5	2081.8	56
57	.9500	311.4	1914.4	329.3	1970.2	347.8	2026.3	366.8	2082.7	57
58	.9667	311.7	1915.4	329.6	1971.1	348.1	2027.2	367.1	2083.7	58
59	.9833	312.0	1916.3	329.9	1972.0	348.4	2028.1	367.4	2084.6	59

Use 100' Chords up to 8° Curves Use 25' Chords up to 32° Curves
Use 50' Chords up to 16° Curves Use 10' Chords above 32° Curves

Minutes	Dec. of Degree	40°		41°		42°		43°		Minutes
		Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	
0	.0000	367.7	2085.5	387.4	2142.3	407.7	2199.5	428.6	2257.1	0
1	.0167	368.0	2086.4	387.8	2143.2	408.0	2200.4	429.0	2258.0	1
2	.0333	368.4	2087.4	388.1	2144.2	408.3	2201.4	429.3	2259.0	2
3	.0500	368.7	2088.3	388.5	2145.1	408.7	2202.3	429.7	2260.0	3
4	.0667	369.0	2089.3	388.8	2146.1	409.0	2203.3	430.0	2261.0	4
5	.0833	369.4	2090.2	389.1	2147.0	409.4	2204.3	430.4	2261.9	5
6	.1000	369.7	2091.2	389.4	2148.0	409.7	2205.3	430.7	2262.9	6
7	.1167	370.0	2092.1	389.8	2148.9	410.1	2206.2	431.1	2263.8	7
8	.1333	370.3	2093.1	390.1	2149.9	410.4	2207.2	431.4	2264.8	8
9	.1500	370.7	2094.0	390.4	2150.9	410.8	2208.1	431.8	2265.7	9
10	.1667	371.0	2095.0	390.7	2151.9	411.1	2209.1	432.1	2266.7	10
11	.1833	371.3	2095.9	391.1	2152.8	411.5	2210.0	432.4	2267.7	11
12	.2000	371.6	2096.9	391.4	2153.8	411.8	2211.0	432.8	2268.7	12
13	.2167	372.0	2097.8	391.8	2154.7	412.2	2211.9	433.2	2269.6	13
14	.2333	372.3	2098.8	392.1	2155.7	412.5	2212.9	433.5	2270.6	14
15	.2500	372.6	2099.7	392.4	2156.6	412.9	2213.9	433.9	2271.5	15
16	.2667	372.9	2100.7	392.7	2157.6	413.2	2214.8	434.2	2272.5	16
17	.2833	373.3	2101.6	393.1	2158.5	413.6	2215.8	434.6	2273.5	17
18	.3000	373.6	2102.6	393.4	2159.5	413.9	2216.8	434.9	2274.5	18
19	.3167	374.0	2103.5	393.7	2160.4	414.3	2217.7	435.3	2275.4	19
20	.3333	374.3	2104.5	394.1	2161.4	414.6	2218.7	435.6	2276.4	20
21	.3500	374.6	2105.4	394.4	2162.3	415.0	2219.6	436.0	2277.3	21
22	.3667	374.9	2106.3	394.7	2163.3	415.3	2220.6	436.3	2278.3	22
23	.3833	375.3	2107.3	395.1	2164.2	415.7	2221.5	436.7	2279.2	23
24	.4000	375.6	2108.2	395.4	2165.2	416.0	2222.5	437.0	2280.2	24
25	.4167	375.9	2109.2	395.8	2166.1	416.3	2223.4	437.4	2281.2	25
26	.4333	376.2	2110.1	396.1	2167.1	416.6	2224.4	437.8	2282.2	26
27	.4500	376.6	2111.0	396.5	2168.0	417.0	2225.4	438.2	2283.1	27
28	.4667	376.9	2112.0	396.8	2169.0	417.3	2226.4	438.5	2284.1	28
29	.4833	377.2	2112.9	397.2	2169.9	417.7	2227.3	438.9	2285.0	29
30	.5000	377.5	2113.9	397.5	2170.9	418.0	2228.3	439.2	2286.0	30
31	.5167	377.9	2114.8	397.8	2171.8	418.4	2229.2	439.6	2287.0	31
32	.5333	378.2	2115.8	398.2	2172.8	418.7	2230.2	439.9	2288.0	32
33	.5500	378.5	2116.7	398.5	2173.7	419.1	2231.1	440.3	2288.9	33
34	.5667	378.8	2117.7	398.8	2174.7	419.4	2232.1	440.6	2289.9	34
35	.5833	379.2	2118.6	399.2	2175.6	419.8	2233.0	441.0	2290.8	35
36	.6000	379.5	2119.6	399.5	2176.6	420.1	2234.0	441.4	2291.8	36
37	.6167	379.8	2120.5	399.9	2177.5	420.5	2235.0	441.8	2292.8	37
38	.6333	380.1	2121.5	400.2	2178.5	420.8	2236.0	442.1	2293.8	38
39	.6500	380.5	2122.4	400.6	2179.4	421.2	2236.9	442.5	2294.7	39
40	.6667	380.8	2123.4	400.9	2180.4	421.5	2237.9	442.8	2295.7	40
41	.6833	381.1	2124.3	401.2	2181.4	421.9	2238.8	443.2	2296.7	41
42	.7000	381.4	2125.3	401.5	2182.4	422.2	2239.8	443.5	2297.7	42
43	.7167	381.8	2126.2	401.9	2183.3	422.6	2240.7	443.9	2298.6	43
44	.7333	382.1	2127.2	402.2	2184.3	422.9	2241.7	444.2	2299.6	44
45	.7500	382.5	2128.1	402.6	2185.2	423.3	2242.6	444.6	2300.5	45
46	.7667	382.8	2129.1	402.9	2186.2	423.6	2243.6	445.0	2301.5	46
47	.7833	383.1	2130.0	403.3	2187.1	424.0	2244.6	445.4	2302.5	47
48	.8000	383.4	2131.0	403.6	2188.1	424.3	2245.6	445.7	2303.5	48
49	.8167	383.8	2131.9	404.0	2189.0	424.7	2246.5	446.1	2304.4	49
50	.8333	384.1	2132.9	404.3	2190.0	425.0	2247.5	446.4	2305.4	50
51	.8500	384.5	2133.8	404.6	2190.9	425.4	2248.4	446.8	2306.3	51
52	.8667	384.8	2134.7	404.9	2191.9	425.7	2249.4	447.1	2307.3	52
53	.8833	385.1	2135.6	405.3	2192.8	426.1	2250.3	447.5	2308.3	53
54	.9000	385.4	2136.6	405.6	2193.8	426.4	2251.3	447.8	2309.3	54
55	.9167	385.8	2137.5	406.0	2194.7	426.8	2252.3	448.2	2310.2	55
56	.9333	386.1	2138.5	406.3	2195.7	427.1	2253.3	448.6	2311.2	56
57	.9500	386.5	2139.4	406.7	2196.6	427.5	2254.2	449.0	2312.1	57
58	.9667	386.8	2140.4	407.0	2197.6	427.8	2255.2	449.3	2313.1	58
59	.9833	387.1	2141.3	407.4	2198.5	428.2	2256.2	449.7	2314.1	59

Use 100′ Chords up to 8° Curves **Use 25′ Chords up to 32° Curves**
Use 50′ Chords up to 16° Curves **Use 10′ Chords above 32° Curves**

Minutes	Dec. of Degree	44°		45°		46°		47°		Minutes
		Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	
0	.0000	450.0	2315.1	472.1	2373.4	494.8	2432.2	518.3	2491.5	0
1	.0167	450.4	2316.0	472.5	2374.4	495.2	2433.2	518.7	2492.4	1
2	.0333	450.7	2317.0	472.9	2375.4	495.6	2434.2	519.0	2493.4	2
3	.0500	451.1	2318.0	473.3	2376.3	496.0	2435.1	519.4	2494.4	3
4	.0667	451.5	2319.0	473.6	2377.3	496.4	2436.1	519.8	2495.4	4
5	.0833	451.9	2319.9	474.0	2378.3	496.7	2437.1	520.2	2496.4	5
6	.1000	452.2	2320.9	474.4	2379.3	497.2	2438.1	520.6	2497.4	6
7	.1167	452.6	2321.8	474.8	2380.2	497.6	2439.1	521.0	2498.4	7
8	.1333	452.9	2322.8	475.1	2381.2	497.9	2440.1	521.4	2499.4	8
9	.1500	453.3	2323.8	475.5	2382.2	498.3	2441.1	521.8	2500.4	9
10	.1667	453.7	2324.8	475.9	2383.2	498.7	2442.1	522.2	2501.4	10
11	.1833	454.1	2325.7	476.3	2384.2	499.1	2443.0	522.6	2502.4	11
12	.2000	454.4	2326.7	476.6	2385.2	499.5	2444.0	523.0	2503.4	12
13	.2167	454.8	2327.7	477.0	2386.1	499.9	2445.0	523.4	2504.4	13
14	.2333	455.1	2328.7	477.4	2387.1	500.3	2446.0	523.8	2505.4	14
15	.2500	455.5	2329.6	477.8	2388.1	500.7	2447.0	524.2	2506.3	15
16	.2667	455.9	2330.6	478.1	2389.1	501.0	2448.0	524.6	2507.3	16
17	.2833	456.3	2331.6	478.5	2390.0	501.4	2449.0	525.0	2508.3	17
18	.3000	456.6	2332.6	478.9	2391.0	501.8	2449.9	525.4	2509.3	18
19	.3167	457.0	2333.5	479.3	2392.0	502.2	2450.9	525.8	2510.3	19
20	.3333	457.3	2334.5	479.6	2393.0	502.6	2451.9	526.2	2511.3	20
21	.3500	457.7	2335.4	480.0	2393.9	503.0	2452.9	526.6	2512.3	21
22	.3667	458.1	2336.4	480.4	2394.9	503.4	2453.9	527.0	2513.3	22
23	.3833	458.5	2337.4	480.8	2395.9	503.8	2454.9	527.4	2514.3	23
24	.4000	458.8	2338.4	481.1	2396.9	504.1	2455.9	527.8	2515.3	24
25	.4167	459.2	2339.3	481.5	2397.8	504.5	2456.8	528.2	2516.3	25
26	.4333	459.5	2340.3	481.9	2398.8	504.9	2457.8	528.6	2517.3	26
27	.4500	459.9	2341.3	482.3	2399.8	505.3	2458.8	529.0	2518.3	27
28	.4667	460.3	2342.3	482.6	2400.8	505.7	2459.8	529.4	2519.3	28
29	.4833	460.7	2343.2	483.0	2401.8	506.1	2460.8	529.8	2520.2	29
30	.5000	461.0	2344.2	483.4	2402.8	506.5	2461.8	530.2	2521.2	30
31	.5167	461.4	2345.1	483.8	2403.7	506.9	2462.8	530.6	2522.2	31
32	.5333	461.7	2346.1	484.2	2404.7	507.3	2463.8	531.0	2523.2	32
33	.5500	462.1	2347.1	484.6	2405.7	507.7	2464.7	531.4	2524.2	33
34	.5667	462.5	2348.1	484.9	2406.7	508.0	2465.7	531.8	2525.2	34
35	.5833	462.9	2349.0	485.3	2407.6	508.4	2466.7	532.2	2526.2	35
36	.6000	463.2	2350.0	485.7	2408.6	508.8	2467.7	532.6	2527.2	36
37	.6167	463.6	2351.0	486.1	2409.6	509.2	2468.7	533.0	2528.2	37
38	.6333	463.9	2352.0	486.5	2410.6	509.6	2469.7	533.4	2529.2	38
39	.6500	464.3	2352.9	486.9	2411.6	510.0	2470.7	533.8	2530.2	39
40	.6667	464.7	2353.9	487.2	2412.6	510.4	2471.7	534.2	2531.2	40
41	.6833	465.0	2354.9	487.6	2413.5	510.8	2472.6	534.6	2532.2	41
42	.7000	465.4	2355.9	488.0	2414.5	511.1	2473.6	535.0	2533.2	42
43	.7167	465.8	2356.8	488.4	2415.5	511.5	2474.6	535.4	2534.2	43
44	.7333	466.2	2357.8	488.7	2416.5	511.9	2475.6	535.8	2535.2	44
45	.7500	466.5	2358.8	489.1	2417.5	512.3	2476.6	536.2	2536.2	45
46	.7667	466.9	2359.8	489.5	2418.5	512.7	2477.6	536.6	2537.2	46
47	.7833	467.3	2360.7	489.9	2419.4	513.1	2478.6	537.0	2538.2	47
48	.8000	467.7	2361.7	490.3	2420.4	513.5	2479.6	537.4	2539.2	48
49	.8167	468.0	2362.7	490.7	2421.4	513.9	2480.6	537.8	2540.2	49
50	.8333	468.4	2363.7	491.0	2422.4	514.3	2481.6	538.2	2541.2	50
51	.8500	468.8	2364.6	491.4	2423.4	514.7	2482.5	538.6	2542.2	51
52	.8667	469.1	2365.6	491.8	2424.4	515.1	2483.5	539.0	2543.2	52
53	.8833	469.5	2366.6	492.2	2425.3	515.5	2484.5	539.4	2544.2	53
54	.9000	469.9	2367.6	492.5	2426.3	515.9	2485.5	539.8	2545.2	54
55	.9167	470.3	2368.5	492.9	2427.3	516.3	2486.5	540.2	2546.2	55
56	.9333	470.6	2369.5	493.3	2428.3	516.7	2487.5	540.6	2547.2	56
57	.9500	471.0	2370.5	493.7	2429.2	517.1	2488.5	541.0	2548.2	57
58	.9667	471.4	2371.5	494.1	2430.2	517.5	2489.5	541.4	2549.2	58
59	.9833	471.8	2372.4	494.5	2431.2	517.9	2490.5	541.9	2550.1	59

Use 100′ Chords up to 8° Curves   Use 25′ Chords up to 32° Curves
Use 50′ Chords up to 16° Curves   Use 10′ Chords above 32° Curves

Minutes	Dec. of Degree	48° Ext.	48° Tan.	49° Ext.	49° Tan.	50° Ext.	50° Tan.	51° Ext.	51° Tan.	Minutes
0	.0000	542.3	2551.1	567.0	2611.3	592.4	2671.9	618.5	2733.0	0
1	.0167	542.7	2552.1	567.4	2612.3	592.8	2672.9	618.9	2734.1	1
2	.0333	543.1	2553.1	567.8	2613.3	593.2	2673.9	619.3	2735.1	2
3	.0500	543.5	2554.1	568.3	2614.3	593.7	2675.0	619.8	2736.1	3
4	0667	543.9	2555.1	568.7	2615.3	594.1	2676.0	620.2	2737.1	4
5	.0833	544.3	2556.1	569.1	2616.3	594.5	2677.0	620.7	2738.2	5
6	.1000	544.7	2557.1	569.5	2617.3	594.9	2678.0	621.1	2739.2	6
7	.1167	545.1	2558.1	569.9	2618.3	595.4	2679.0	621.6	2740.2	7
8	.1333	545.5	2559.1	570.3	2619.3	595.8	2680.0	622.0	2741.2	8
9	.1500	546.0	2560.1	570.8	2620.4	596.2	2681.1	622.5	2742.3	9
10	.1667	546.4	2561.1	571.2	2621.4	596.7	2682.1	622.9	2743.3	10
11	.1833	546.8	2562.1	571.6	2622.4	597.1	2683.1	623.3	2744.3	11
12	.2000	547.2	2563.1	572.0	2623.4	597.5	2684.1	623.7	2745.3	12
13	.2167	547.6	2564.1	572.4	2624.4	598.0	2685.1	624.2	2746.4	13
14	.2333	548.0	2565.1	572.8	2625.4	598.4	2686.1	624.6	2747.4	14
15	.2500	548.4	2566.1	573.3	2626.4	598.9	2687.2	625.1	2748.4	15
16	.2667	548.8	2567.1	573.7	2627.4	599.3	2688.2	625.5	2749.4	16
17	.2833	549.2	2568.1	574.1	2628.4	599.7	2689.2	626.0	2750.5	17
18	.3000	549.6	2569.1	574.5	2629.4	600.1	2690.2	626.4	2751.5	18
19	.3167	550.1	2570.1	574.9	2630.4	600.6	2691.3	626.9	2752.5	19
20	.3333	550.5	2571.1	575.3	2631.4	601.0	2692.3	627.3	2753.5	20
21	.3500	550.9	2572.1	575.8	2632.5	601.5	2693.3	627.8	2754.6	21
22	.3667	551.3	2573.1	576.2	2633.5	601.9	2694.3	628.2	2755.6	22
23	.3833	551.7	2574.1	576.6	2634.5	602.3	2695.3	628.7	2756.7	23
24	.4000	552.1	2575.1	577.0	2635.5	602.7	2696.3	629.1	2757.7	24
25	.4167	552.5	2576.1	577.5	2636.5	603.2	2697.4	629.6	2758.7	25
26	.4333	552.9	2577.1	577.9	2637.5	603.6	2698.4	630.0	2759.7	26
27	.4500	553.3	2578.1	578.3	2638.5	604.1	2699.4	630.5	2760.8	27
28	.4667	553.7	2579.1	578.7	2639.5	604.5	2700.4	630.9	2761.8	28
29	.4833	554.2	2580.1	579.2	2640.5	604.9	2701.4	631.4	2762.8	29
30	.5000	554.6	2581.1	579.6	2641.5	605.3	2702.4	631.8	2763.8	30
31	.5167	555.0	2582.1	580.0	2642.5	605.8	2703.5	632.3	2764.9	31
32	.5333	555.4	2583.1	580.4	2643.5	606.2	2704.5	632.7	2765.9	32
33	.5500	555.8	2584.1	580.9	2644.6	606.6	2705.5	633.2	2766.9	33
34	.5667	556.2	2585.1	581.3	2645.6	607.0	2706.5	633.6	2767.9	34
35	.5833	556.6	2586.2	581.7	2646.6	607.5	2707.6	634.1	2769.0	35
36	.6000	557.0	2587.2	582.1	2647.6	607.9	2708.6	634.5	2770.0	36
37	.6167	557.4	2588.2	582.6	2648.6	608.4	2709.6	634.9	2771.0	37
38	.6333	557.8	2589.2	583.0	2649.6	608.8	2710.6	635.3	2772.0	38
39	.6500	558.3	2590.2	583.4	2650.6	609.3	2711.6	635.8	2773.1	39
40	.6667	558.7	2591.2	583.8	2651.6	609.7	2712.6	636.2	2774.1	40
41	.6833	559.1	2592.2	584.3	2652.7	610.1	2713.7	636.7	2775.2	41
42	.7000	559.5	2593.2	584.7	2653.7	610.5	2714.7	637.1	2776.2	42
43	.7167	559.9	2594.2	585.1	2654.7	611.0	2715.7	637.5	2777.2	43
44	.7333	560.3	2595.2	585.5	2655.7	611.4	2716.7	638.0	2778.2	44
45	.7500	560.8	2596.2	586.0	2656.7	611.9	2717.8	638.5	2779.3	45
46	.7667	561.2	2597.2	586.4	2657.7	612.3	2718.8	638.9	2780.3	46
47	.7833	561.6	2598.2	586.8	2658.7	612.8	2719.8	639.4	2781.3	47
48	.8000	562.0	2599.2	587.2	2659.7	613.2	2720.8	639.8	2782.3	48
49	.8167	562.4	2600.2	587.7	2660.8	613.7	2721.8	640.3	2783.4	49
50	.8333	562.8	2601.2	588.1	2661.8	614.1	2722.8	640.7	2784.4	50
51	.8500	563.3	2602.2	588.5	2662.8	614.5	2723.9	641.2	2785.4	51
52	.8667	563.7	2603.2	588.9	2663.8	614.9	2724.9	641.6	2786.4	52
53	.8833	564.1	2604.2	589.4	2664.8	615.4	2725.9	642.1	2787.5	53
54	.9000	564.5	2605.2	589.8	2665.8	615.8	2726.9	642.5	2788.5	54
55	.9167	564.9	2606.2	590.2	2666.8	616.3	2728.0	643.0	2789.6	55
56	.9333	565.3	2607.2	590.6	2667.8	616.7	2729.0	643.4	2790.6	56
57	.9500	565.8	2608.3	591.1	2668.9	617.2	2730.0	643.9	2791.6	57
58	.9667	566.2	2609.3	591.5	2669.9	617.6	2731.0	644.3	2792.6	58
59	.9833	566.6	2610.3	592.0	2670.9	618.1	2732.0	644.8	2793.7	59

Use 100′ Chords up to 8° Curves
Use 50′ Chords up to 16° Curves
Use 25′ Chords up to 32° Curves
Use 10′ Chords above 32° Curves

Minutes	Dec. of Degree	52°		53°		54°		55°		Minutes
		Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	
0	.0000	645.2	2794.7	672.7	2856.9	700.9	2919.5	729.9	2982.8	0
1	.0167	645.7	2795.8	673.2	2857.9	701.4	2920.6	730.4	2983.9	1
2	.0333	646.1	2796.8	673.7	2858.9	701.9	2921.6	730.9	2984.9	2
3	.0500	646.6	2797.8	674.2	2860.0	702.4	2922.7	731.4	2986.0	3
4	.0667	647.0	2798.8	674.6	2861.0	702.8	2923.8	731.9	2987.1	4
5	.0833	647.5	2799.9	675.1	2862.1	703.3	2924.9	732.4	2988.2	5
6	.1000	647.9	2800.9	675.5	2863.1	703.8	2925.9	732.9	2989.2	6
7	.1167	648.4	2802.0	676.0	2864.2	704.3	2927.0	733.4	2990.3	7
8	.1333	648.9	2803.0	676.4	2865.2	704.8	2928.0	733.8	2991.3	8
9	.1500	649.4	2804.0	676.9	2866.3	705.3	2929.1	734.3	2992.4	9
10	.1667	649.8	2805.0	677.4	2867.3	705.7	2930.1	734.8	2993.4	10
11	.1833	650.3	2806.1	677.9	2868.4	706.2	2931.2	735.3	2994.5	11
12	.2000	650.7	2807.1	678.3	2869.4	706.7	2932.2	735.8	2995.5	12
13	.2167	651.2	2808.2	678.8	2870.5	707.2	2933.3	736.3	2996.6	13
14	.2333	651.6	2809.2	679.2	2871.5	707.7	2934.3	736.8	2997.7	14
15	.2500	652.1	2810.2	679.7	2872.5	708.2	2935.4	737.3	2998.8	15
16	.2667	652.5	2811.2	680.2	2873.5	708.6	2936.4	737.8	2999.8	16
17	.2833	653.0	2812.3	680.7	2874.6	709.1	2937.5	738.2	3000.9	17
18	.3000	653.4	2813.3	681.1	2875.6	709.6	2938.5	738.7	3001.9	18
19	.3167	653.9	2814.4	681.6	2876.7	710.1	2939.6	739.2	3003.0	19
20	.3333	654.3	2815.4	682.0	2877.7	710.5	2940.6	739.7	3004.0	20
21	.3500	654.8	2816.4	682.5	2878.8	711.0	2941.7	740.2	3005.1	21
22	.3667	655.2	2817.4	683.0	2879.8	711.5	2942.7	740.7	3006.2	22
23	.3833	655.7	2818.5	683.5	2880.9	712.0	2943.8	741.2	3007.3	23
24	.4000	656.2	2819.5	683.9	2881.9	712.5	2944.8	741.7	3008.3	24
25	.4167	656.7	2820.6	684.4	2883.0	713.0	2945.9	742.2	3009.4	25
26	.4333	657.1	2821.6	684.9	2884.0	713.4	2946.9	742.7	3010.4	26
27	.4500	657.6	2822.6	685.4	2885.1	713.9	2948.0	743.2	3011.5	27
28	.4667	658.0	2823.6	685.8	2886.1	714.4	2949.0	743.7	3012.5	28
29	.4833	658.5	2824.7	686.3	2887.1	714.9	2950.1	744.2	3013.6	29
30	.5000	658.9	2825.7	686.7	2888.1	715.3	2951.1	744.7	3014.7	30
31	.5167	659.4	2826.8	687.2	2889.2	715.8	2952.2	745.2	3015.8	31
32	.5333	659.8	2827.8	687.7	2890.2	716.3	2953.2	745.7	3016.8	32
33	.5500	660.3	2828.8	688.2	2891.3	716.8	2954.3	746.2	3017.9	33
34	.5667	660.7	2829.8	688.6	2892.3	717.3	2955.3	746.7	3018.9	34
35	.5833	661.2	2830.9	689.1	2893.4	717.8	2956.4	747.2	3020.0	35
36	.6000	661 6	2831.9	689.6	2894.4	718.2	2957.5	747.7	3021.1	36
37	.6167	662.1	2833.0	690.1	2895.5	718.7	2958.6	748.2	3022.1	37
38	.6333	662.5	2834.0	690.5	2896.5	719.2	2959.6	748.7	3023.2	38
39	.6500	663.0	2835.1	691.0	2897.6	719.7	2960.7	749.2	3024.3	39
40	.6667	663.5	2836.1	691.5	2898.6	720.2	2961.7	749.7	3025.3	40
41	.6833	664.0	2837.2	692.0	2899.7	720.7	2962.8	750.2	3026.4	41
42	.7000	664.4	2838.2	692.4	2900.7	721.1	2963.8	750.7	3027.5	42
43	.7167	664.9	2839.2	692.9	2901.8	721.6	2964.9	751.2	3028.6	43
44	.7333	665.3	2840.2	693.4	2902.8	722.1	2965.9	751.7	3029.6	44
45	.7500	665.8	2841.3	693.9	2903.9	722.6	2967.0	752.2	3030.7	45
46	.7667	666.2	2842.3	694.3	2904.9	723.1	2968.0	752.6	3031.7	46
47	.7833	666.7	2843.4	694.8	2906.0	723.6	2969.1	753.1	3032.8	47
48	.8000	667.2	2844.4	695.3	2907.0	724.1	2970.1	753.6	3033.8	48
49	.8167	667.7	2845.5	695.8	2908.1	724.6	2971.2	754.1	3035.0	49
50	.8333	668.1	2846.5	696.2	2909.1	725.0	2972.2	754.6	3036.0	50
51	.8500	668.6	2847.5	696.7	2910.2	725.5	2973.3	755.1	3037.1	51
52	.8667	669.0	2848.5	697.1	2911.2	726.0	2974.4	755.6	3038.1	52
53	.8833	669.5	2849.6	697.6	2912.3	726.5	2975.5	756.1	3039.2	53
54	.9000	669.9	2850.6	698.1	2913.3	727.0	2976.5	756.6	3040.2	54
55	.9167	670.4	2851.7	698.6	2914.4	727.5	2977.6	757.1	3041.3	55
56	.9333	670.9	2852.7	699.0	2915.4	728.0	2978.6	757.6	3042.4	56
57	.9500	671.4	2853.8	699.5	2916.5	728.5	2979.7	758.1	3043.5	57
58	.9667	671.8	2854.8	700.0	2917.5	729.0	2980.7	758.6	3044.5	58
59	.9833	672.3	2855.9	700.5	2918.5	729.5	2981.8	759.1	3045.6	59

Use 100′ Chords up to 8° Curves Use 25′ Chords up to 32° Curves
Use 50′ Chords up to 16° Curves Use 10′ Chords above 32° Curves

Minutes	Dec. of Degree	56°		57°		58°		59°		Minutes
		Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	
0	.0000	759.6	3046.6	790.2	3111.1	821.4	3176.1	853.5	3241.9	0
1	.0167	760.1	3047.7	790.7	3112.2	821.9	3177.2	854.0	3243.0	1
2	.0333	760.6	3048.8	791.2	3113.3	822.5	3178.3	854.6	3244.1	2
3	.0500	761.1	3049.9	791.7	3114.4	823.0	3179.4	855.1	3245.2	3
4	.0667	761.6	3050.9	792.2	3115.4	823.5	3180.5	855.7	3246.3	4
5	.0833	762.2	3052.0	792.8	3116.5	824.1	3181.6	856.2	3247.4	5
6	.1000	762.7	3053.1	793.3	3117.6	824.6	3182.7	856.8	3248.5	6
7	.1167	763.2	3054.2	793.8	3118.7	825.2	3183.8	857.3	3249.6	7
8	.1333	763.7	3055.2	794.3	3119.7	825.7	3184.9	857.9	3250.7	8
9	.1500	764.2	3056.3	794.8	3120.8	826.2	3186.0	858.5	3251.8	9
10	.1667	764.7	3057.4	795.3	3121.9	826.7	3187.1	859.0	3252.9	10
11	.1833	765.2	3058.5	795.8	3123.0	827.3	3188.2	859.5	3254.0	11
12	.2000	765.7	3059.5	796.3	3124.1	827.8	3189.2	860.0	3255.1	12
13	.2167	766.2	3060.6	796.9	3125.2	828.4	3190.3	860.6	3256.2	13
14	.2333	766.7	3061.6	797.4	3126.2	828.9	3191.4	861.1	3257.3	14
15	.2500	767.2	3062.7	797.9	3127.3	829.4	3192.5	861.7	3258.4	15
16	.2667	767.7	3063.8	798.4	3128.4	829.9	3193.6	862.2	3259.5	16
17	.2833	768.2	3064.9	798.9	3129.5	830.5	3194.7	862.8	3260.6	17
18	.3000	768.7	3065.9	799.4	3130.6	831.0	3195.8	863.3	3261.7	18
19	.3167	769.2	3067.0	799.9	3131.7	831.5	3196.9	863.8	3262.8	19
20	.3333	769.7	3068.1	800.5	3132.7	832.1	3198.0	864.4	3263.9	20
21	.3500	770.3	3069.2	801.0	3133.8	832.5	3199.1	864.9	3265.0	21
22	.3667	770.8	3070.2	801.5	3134.9	833.1	3200.2	865.5	3266.1	22
23	.3833	771.3	3071.3	802.0	3136.0	833.6	3201.3	866.0	3267.2	23
24	.4000	771.8	3072.4	802.5	3137.0	834.2	3202.4	866.6	3268.3	24
25	.4167	772.3	3073.5	803.1	3138.1	834.7	3203.5	867.1	3269.4	25
26	.4333	772.8	3074.5	803.6	3139.2	835.3	3204.5	867.7	3270.5	26
27	.4500	773.3	3075.6	804.2	3140.3	835.8	3205.6	868.2	3271.6	27
28	.4667	773.8	3076.6	804.7	3141.4	836.3	3206.7	868.8	3272.7	28
29	.4833	774.3	3077.7	805.2	3142.5	836.8	3207.8	869.3	3273.8	29
30	.5000	774.8	3078.8	805.7	3143.5	837.4	3208.9	869.9	3274.9	30
31	.5167	775.3	3079.9	806.3	3144.6	837.8	3210.0	870.5	3276.0	31
32	.5333	775.8	3080.9	806.8	3145.7	838.4	3211.1	871.0	3277.1	32
33	.5500	776.3	3082.0	807.3	3146.8	838.9	3212.2	871.6	3278.2	33
34	.5667	776.8	3083.1	807.8	3147.9	839.5	3213.3	872.1	3279.4	34
35	.5833	777.3	3084.2	808.3	3149.0	840.0	3214.4	872.7	3280.5	35
36	.6000	777.8	3085.2	808.8	3150.0	840.6	3215.5	873.2	3281.6	36
37	.6167	778.4	3086.3	809.4	3151.1	841.1	3216.6	873.8	3282.7	37
38	.6333	778.9	3087.4	809.9	3152.2	841.6	3217.7	874.3	3283.8	38
39	.6500	779.4	3088.5	810.4	3153.3	842.1	3218.8	874.9	3284.9	39
40	.6667	779.9	3089.6	810.9	3154.4	842.7	3219.9	875.4	3286.0	40
41	.6833	780.4	3090.7	811.5	3155.5	843.1	3221.0	876.0	3287.1	41
42	.7000	780.9	3091.7	812.0	3156.6	843.8	3222.1	876.5	3288.2	42
43	.7167	781.4	3092.8	812.5	3157.7	844.2	3223.2	877.0	3289.3	43
44	.7333	781.9	3093.9	813.0	3158.7	844.9	3224.3	877.6	3290.5	44
45	.7500	782.5	3095.0	813.6	3159.8	845.5	3225.4	878.1	3291.6	45
46	.7667	783.0	3096.0	814.1	3160.9	846.0	3226.5	878.7	3292.7	46
47	.7833	783.5	3097.1	814.6	3162.0	846.5	3227.6	879.2	3293.8	47
48	.8000	784.0	3098.2	815.1	3163.1	847.0	3228.7	879.8	3294.9	48
49	.8167	784.5	3099.3	815.7	3164.2	847.6	3229.8	880.3	3296.0	49
50	.8333	785.0	3100.3	816.2	3165.3	848.1	3230.9	880.9	3297.1	50
51	.8500	785.5	3101.4	816.7	3166.4	848.7	3232.0	881.5	3298.2	51
52	.8667	786.0	3102.5	817.2	3167.4	849.2	3233.1	882.0	3299.3	52
53	.8833	786.6	3103.6	817.8	3168.5	849.8	3234.2	882.6	3300.4	53
54	.9000	787.1	3104.6	818.3	3169.6	850.3	3235.3	883.1	3301.5	54
55	.9167	787.6	3105.7	818.8	3170.7	850.9	3236.4	883.7	3302.6	55
56	.9333	788.1	3106.8	819.3	3171.8	851.4	3237.5	884.2	3303.8	56
57	.9500	788.6	3107.9	819.9	3172.9	852.0	3238.6	884.8	3304.9	57
58	.9667	789.1	3108.9	820.4	3174.0	852.5	3239.7	885.3	3306.0	58
59	.9833	789.7	3110.0	820.9	3175.1	853.0	3240.8	885.9	3307.1	59

Use 100′ Chords up to 8° Curves Use 25′ Chords up to 32° Curves
Use 50′ Chords up to 16° Curves Use 10′ Chords above 32° Curves

Minutes	Dec. of Degree	60° Ext.	60° Tan.	61° Ext.	61° Tan.	62° Ext.	62° Tan.	63° Ext.	63° Tan.	Minutes
0	.0000	886.4	3308.1	920.2	3375.0	954.8	3442.9	990.3	3511.3	0
1	.0167	886.9	3309.3	920.8	3376.2	955.4	3444.1	990.9	3512.4	1
2	.0333	887.5	3310.4	921.4	3377.4	956.0	3445.2	991.5	3513.6	2
3	.0500	888.1	3311.5	922.0	3378.5	956.6	3446.3	992.1	3514.8	3
4	.0667	888.7	3312.7	922.5	3379.7	957.2	3447.5	992.7	3515.9	4
5	.0833	889.3	3313.8	923.0	3380.8	957.7	3448.6	993.3	3517.1	5
6	.1000	889.8	3314.9	923.6	3381.9	958.3	3449.7	993.9	3518.2	6
7	.1167	890.3	3316.0	924.2	3383.1	958.9	3450.9	994.5	3519.3	7
8	.1333	890.9	3317.1	924.8	3384.2	959.5	3452.0	995.1	3520.5	8
9	.1500	891.5	3318.2	925.3	3385.3	960.1	3453.2	995.7	3521.6	9
10	.1667	892.0	3319.3	925.9	3386.4	960.7	3454.3	996.3	3522.8	10
11	.1833	892.6	3320.5	926.5	3387.5	961.3	3455.4	996.9	3524.0	11
12	.2000	893.1	3321.6	927.1	3388.7	961.9	3456.6	997.5	3525.1	12
13	.2167	893.7	3322.7	927.6	3389.8	962.4	3457.7	998.1	3526.3	13
14	.2333	894.3	3323.8	928.2	3391.0	963.0	3458.8	998.7	3527.4	14
15	.2500	894.8	3324.9	928.7	3392.1	963.6	3460.0	999.3	3528.6	15
16	.2667	895.4	3326.0	929.3	3393.2	964.2	3461.1	999.9	3529.7	16
17	.2833	895.9	3327.1	929.9	3394.3	964.8	3462.3	1000.5	3530.9	17
18	.3000	896.5	3328.3	930.5	3395.4	965.4	3463.4	1001.1	3532.0	18
19	.3167	897.0	3329.4	931.0	3396.6	966.0	3464.6	1001.7	3533.2	19
20	.3333	897.6	3330.5	931.6	3397.7	966.6	3465.7	1002.3	3534.3	20
21	.3500	898.2	3331.6	932.2	3398.8	967.2	3466.8	1002.9	3535.4	21
22	.3667	898.8	3332.7	932.8	3399.9	967.8	3468.0	1003.5	3536.6	22
23	.3833	899.3	3333.8	933.3	3401.1	968.3	3469.1	1004.1	3537.8	23
24	.4000	899.9	3334.9	933.9	3402.2	968.9	3470.2	1004.7	3538.9	24
25	.4167	900.5	3336.1	934.5	3403.3	969.5	3471.3	1005.3	3540.0	25
26	.4333	901.0	3337.2	935.1	3404.4	970.1	3472.5	1005.9	3541.2	26
27	.4500	901.6	3338.3	935.7	3405.6	970.7	3473.6	1006.5	3542.3	27
28	.4667	902.2	3339.4	936.2	3406.7	971.3	3474.7	1007.1	3543.5	28
29	.4833	902.7	3340.5	936.8	3407.8	971.9	3475.9	1007.7	3544.6	29
30	.5000	903.3	3341.6	937.4	3409.0	972.5	3477.0	1008.4	3545.8	30
31	.5167	903.8	3342.7	938.0	3410.1	973.0	3478.1	1009.0	3546.9	31
32	.5333	904.4	3343.9	938.6	3411.2	973.6	3479.3	1009.6	3548.1	32
33	.5500	905.0	3345.0	939.1	3412.3	974.2	3480.5	1010.2	3549.2	33
34	.5667	905.5	3346.1	939.7	3413.5	974.8	3481.6	1010.8	3550.4	34
35	.5833	906.1	3347.2	940.3	3414.6	975.4	3482.7	1011.4	3551.6	35
36	.6000	906.6	3348.3	940.9	3415.7	976.0	3483.9	1012.0	3552.7	36
37	.6167	907.2	3349.5	941.5	3416.8	976.6	3485.0	1012.6	3553.8	37
38	.6333	907.7	3350.6	942.1	3418.0	977.2	3486.1	1013.2	3555.0	38
39	.6500	908.3	3351.7	942.6	3419.1	977.8	3487.4	1013.9	3556.2	39
40	.6667	908.8	3352.8	943.2	3420.3	978.4	3488.5	1014.5	3557.3	40
41	.6833	909.4	3353.9	943.8	3421.4	979.0	3489.6	1015.1	3558.4	41
42	.7000	910.0	3355.0	944.4	3422.5	979.6	3490.7	1015.7	3559.6	42
43	.7167	910.6	3356.2	944.9	3423.6	980.2	3491.9	1016.3	3560.8	43
44	.7333	911.1	3357.3	945.5	3424.8	980.8	3493.0	1016.9	3562.0	44
45	.7500	911.7	3358.4	946.1	3426.0	981.4	3494.2	1017.5	3563.1	45
46	.7667	912.3	3359.5	946.7	3427.1	982.0	3495.3	1018.2	3564.3	46
47	.7833	912.8	3360.6	947.2	3428.2	982.6	3496.4	1018.7	3565.5	47
48	.8000	913.4	3361.8	947.8	3429.3	983.2	3497.6	1019.3	3566.6	48
49	.8167	914.0	3362.9	948.4	3430.4	983.8	3498.7	1020.0	3567.7	49
50	.8333	914.5	3364.0	949.0	3431.6	984.4	3499.9	1020.6	3568.9	50
51	.8500	915.1	3365.1	949.6	3432.8	985.0	3501.0	1021.2	3570.0	51
52	.8667	915.7	3366.2	950.2	3433.9	985.5	3502.2	1021.8	3571.2	52
53	.8833	916.2	3367.3	950.7	3435.0	986.1	3503.3	1022.4	3572.3	53
54	.9000	916.8	3368.5	951.3	3436.1	986.7	3504.5	1023.0	3573.5	54
55	.9167	917.4	3369.6	951.9	3437.3	987.3	3505.6	1023.6	3574.6	55
56	.9333	918.0	3370.7	952.5	3438.4	987.9	3506.8	1024.2	3575.8	56
57	.9500	918.6	3371.9	953.0	3439.6	988.5	3507.9	1024.8	3576.9	57
58	.9667	919.1	3373.0	953.6	3440.7	989.1	3509.0	1025.4	3578.1	58
59	.9833	919.6	3374.1	954.2	3441.8	989.7	3510.1	1026.1	3579.3	59

Use 100′ Chords up to 8° Curves
Use 50′ Chords up to 16° Curves
Use 25′ Chords up to 32° Curves
Use 10′ Chords above 32° Curves

Minutes	Dec. of Degree	64° Ext.	64° Tan.	65° Ext.	65° Tan.	66° Ext.	66° Tan	67° Ext.	67° Tan.	Minutes
0	.0000	1026.7	3580.4	1064.0	3650.4	1102.2	3721.1	1141.5	3792.6	0
1	.0167	1027.3	3581.6	1064.6	3651.6	1102.9	3722.3	1142.2	3793.8	1
2	.0333	1027.9	3582.8	1065.2	3652.8	1103.5	3723.4	1142.8	3795.0	2
3	.0500	1028.6	3583.9	1065.9	3654.0	1104.2	3724.6	1143.5	3796.2	3
4	.0667	1029.2	3585.1	1066.5	3655.1	1104.8	3725.8	1144.1	3797.4	4
5	.0833	1029.8	3586.3	1067.1	3656.3	1105.5	3727.0	1144.8	3798.6	5
6	.1000	1030.4	3587.4	1067.7	3657.5	1106.1	3728.2	1145.4	3799.8	6
7	.1167	1031.1	3588.6	1068.4	3658.6	1106.8	3729.4	1146.1	3801.0	7
8	.1333	1031.7	3589.7	1069.0	3659.8	1107.4	3730.6	1146.7	3802.2	8
9	.1500	1032.3	3590.9	1069.6	3661.0	1108.1	3731.7	1147.4	3803.4	9
10	.1667	1032.9	3592.1	1070.2	3662.2	1108.7	3732.9	1148.1	3804.6	10
11	.1833	1033.5	3593.3	1070.9	3663.4	1109.4	3734.1	1148.8	3805.8	11
12	.2000	1034.1	3594.4	1071.5	3664.5	1110.0	3735.3	1149.4	3807.0	12
13	.2167	1034.8	3595.5	1072.1	3665.7	1110.7	3736.5	1150.1	3808.2	13
14	.2333	1035.4	3596.7	1072.7	3666.9	1111.3	3737.7	1150.7	3809.4	14
15	.2500	1036.0	3597.9	1073.4	3668.0	1112.0	3738.9	1151.4	3810.6	15
16	.2667	1036.6	3599.1	1074.0	3669.2	1112.6	3740.1	1152.0	3811.8	16
17	.2833	1037.3	3600.3	1074.6	3670.4	1113.3	3741.3	1152.7	3813.0	17
18	.3000	1037.9	3601.4	1075.2	3671.6	1113.9	3742.4	1153.3	3814.2	18
19	.3167	1038.5	3602.6	1075.9	3672.8	1114.6	3743.6	1154.0	3815.4	19
20	.3333	1039.1	3603.7	1076.6	3673.9	1115.2	3744.8	1154.7	3816.6	20
21	.3500	1039.7	3604.8	1077.2	3675.0	1115.9	3746.0	1155.4	3817.8	21
22	.3667	1040.3	3606.0	1077.8	3676.2	1116.5	3747.2	1156.0	3819.0	22
23	.3833	1041.0	3607.2	1078.5	3677.4	1117.2	3748.4	1156.7	3820.2	23
24	.4000	1041.6	3608.4	1079.1	3678.6	1117.8	3749.6	1157.4	3821.4	24
25	.4167	1042.2	3609.5	1079.8	3679.7	1118.5	3750.7	1158.1	3822.6	25
26	.4333	1042.8	3610.7	1080.4	3680.9	1119.1	3751.9	1158.7	3823.8	26
27	.4500	1043.5	3611.9	1081.1	3682.1	1119.8	3753.1	1159.4	3825.0	27
28	.4667	1044.1	3613.0	1081.7	3683.3	1120.4	3754.3	1160.1	3826.2	28
29	.4833	1044.7	3614.1	1082.4	3684.5	1121.1	3755.5	1160.8	3827.4	29
30	.5000	1045.3	3615.3	1083.0	3685.6	1121.7	3756.7	1161.4	3828.6	30
31	.5167	1045.9	3616.5	1083.6	3686.8	1122.3	3757.9	1162.1	3829.8	31
32	.5333	1046.5	3617.7	1084.2	3688.0	1123.0	3759.1	1162.8	3831.0	32
33	.5500	1047.2	3618.9	1084.9	3689.2	1123.7	3760.3	1163.5	3832.2	33
34	.5667	1047.8	3620.0	1085.5	3690.4	1124.3	3761.5	1164.1	3833.4	34
35	.5833	1048.4	3621.1	1086.2	3691.6	1125.0	3762.7	1164.8	3834.6	35
36	.6000	1049.0	3622.3	1086.8	3692.7	1125.6	3763.9	1165.5	3835.9	36
37	.6167	1049.7	3623.5	1087.5	3693.9	1126.3	3765.1	1166.2	3837.1	37
38	.6333	1050.3	3624.7	1088.1	3695.1	1126.9	3766.3	1166.8	3838.3	38
39	.6500	1050.9	3625.8	1088.8	3696.2	1127.6	3767.5	1167.5	3839.5	39
40	.6667	1051.5	3627.0	1089.4	3697.4	1128.3	3768.7	1168.2	3840.7	40
41	.6833	1052.1	3628.2	1090.0	3698.6	1129.0	3769.9	1168.9	3841.9	41
42	.7000	1052.7	3629.4	1090.6	3699.8	1129.6	3771.0	1169.5	3843.1	42
43	.7167	1053.4	3630.5	1091.3	3701.0	1130.3	3772.2	1170.2	3844.3	43
44	.7333	1054.0	3631.7	1091.9	3702.2	1130.9	3773.4	1170.9	3845.5	44
45	.7500	1054.6	3632.8	1092.6	3703.3	1131.6	3774.6	1171.6	3846.7	45
46	.7667	1055.2	3634.0	1093.2	3704.5	1132.2	3775.8	1172.2	3847.9	46
47	.7833	1055.9	3635.2	1093.9	3705.7	1132.9	3777.0	1172.9	3849.1	47
48	.8000	1056.5	3636.4	1094.5	3706.9	1133.5	3778.2	1173.6	3850.4	48
49	.8167	1057.1	3637.5	1095.2	3708.1	1134.2	3779.4	1174.3	3851.6	49
50	.8333	1057.7	3638.7	1095.8	3709.3	1134.9	3780.6	1174.9	3852.8	50
51	.8500	1058.4	3639.9	1096.4	3710.5	1135.6	3781.8	1175.6	3854.0	51
52	.8667	1059.0	3641.1	1097.0	3711.6	1136.2	3783.0	1176.3	3855.2	52
53	.8833	1059.6	3642.3	1097.7	3712.8	1136.9	3784.2	1177.0	3856.4	53
54	.9000	1060.2	3643.4	1098.3	3714.0	1137.5	3785.4	1177.6	3857.6	54
55	.9167	1060.9	3644.6	1099.0	3715.1	1138.2	3786.6	1178.3	3858.8	55
56	.9333	1061.5	3645.7	1099.6	3716.3	1138.8	3787.8	1179.0	3860.0	56
57	.9500	1062.1	3646.9	1100.3	3717.5	1139.5	3789.0	1179.7	3861.2	57
58	.9667	1062.7	3648.1	1100.9	3718.7	1140.1	3790.2	1180.3	3862.5	58
59	.9833	1063.4	3649.2	1101.6	3719.9	1140.8	3791.4	1181.0	3863.7	59

Use 100′ Chords up to 8° Curves
Use 50′ Chords up to 16° Curves
Use 25′ Chords up to 32° Curves
Use 10′ Chords above 32° Curves

Minutes	Dec. of Degree	68°		69°		70°		71°		Minutes
		Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	
0	.0000	1181.6	3864.9	1222.9	3938.1	1265.0	4012.1	1308.4	4087.1	0
1	.0167	1182.3	3866.1	1223.6	3939.4	1265.7	4013.4	1309.2	4088.4	1
2	.0333	1183.0	3867.3	1224.3	3940.6	1266.4	4014.6	1309.9	4089.7	2
3	.0500	1183.7	3868.5	1225.0	3941.8	1267.2	4015.9	1310.6	4091.0	3
4	.0667	1184.4	3869.7	1225.7	3943.0	1267.9	4017.1	1311.3	4092.2	4
5	.0833	1185.1	3870.9	1226.4	3944.2	1268.6	4018.4	1312.1	4093.5	5
6	.1000	1185.7	3872.2	1227.1	3945.5	1269.3	4019.6	1312.8	4094.7	6
7	.1167	1186.4	3873.4	1227.8	3946.7	1270.1	4020.8	1313.5	4096.0	7
8	.1333	1187.1	3874.6	1228.5	3947.9	1270.8	4022.1	1314.2	4097.2	8
9	.1500	1187.8	3875.8	1229.2	3949.2	1271.5	4023.4	1315.0	4098.5	9
10	.1667	1188.5	3877.0	1229.9	3950.4	1272.2	4024.6	1315.7	4099.8	10
11	.1833	1189.2	3878.2	1230.6	3951.6	1272.9	4025.8	1316.5	4101.1	11
12	.2000	1189.8	3879.5	1231.3	3952.9	1273.6	4027.1	1317.2	4102.3	12
13	.2167	1190.5	3880.7	1232.0	3954.1	1274.4	4028.4	1317.9	4103.6	13
14	.2333	1191.2	3881.9	1232.7	3955.3	1275.1	4029.6	1318.6	4104.8	14
15	.2500	1191.9	3883.1	1233.4	3956.6	1275.8	4030.8	1319.4	4106.1	15
16	.2667	1192.6	3884.3	1234.1	3957.8	1276.5	4032.1	1320.1	4107.3	16
17	.2833	1193.3	3885.6	1234.8	3959.0	1277.3	4033.4	1320.8	4108.6	17
18	.3000	1193.9	3886.8	1235.5	3960.2	1278.0	4034.6	1321.5	4109.8	18
19	.3167	1194.6	3888.0	1236.2	3961.5	1278.7	4035.9	1322.3	4111.1	19
20	.3333	1195.3	3889.2	1236.9	3962.7	1279.4	4037.1	1323.0	4112.4	20
21	.3500	1196.0	3890.4	1237.6	3964.0	1280.1	4038.4	1323.7	4113.7	21
22	.3667	1196.7	3891.6	1238.3	3965.2	1280.8	4039.6	1324.4	4114.9	22
23	.3833	1197.4	3892.9	1239.0	3966.4	1281.6	4040.9	1325.2	4116.2	23
24	.4000	1198.0	3894.1	1239.7	3967.6	1282.3	4042.1	1325.9	4117.4	24
25	.4167	1198.7	3895.3	1240.4	3968.9	1283.0	4043.4	1326.7	4118.7	25
26	.4333	1199.4	3896.5	1241.1	3970.1	1283.7	4044.6	1327.4	4119.9	26
27	.4500	1200.1	3897.7	1241.8	3971.3	1284.5	4045.9	1328.2	4121.2	27
28	.4667	1200.8	3898.9	1242.5	3972.5	1285.2	4047.1	1228.9	4122.4	28
29	.4833	1201.5	3900.2	1243.2	3973.8	1285.9	4048.4	1329.7	4123.7	29
30	.5000	1202.1	3901.4	1243.9	3975.0	1286.6	4049.6	1330.4	4125.0	30
31	.5167	1202.8	3902.6	1244.6	3976.3	1287.3	4050.9	1331.1	4126.3	31
32	.5333	1203.5	3903.8	1245.3	3977.5	1288.0	4052.1	1331.8	4127.5	32
33	.5500	1204.2	3905.0	1246.0	3978.8	1288.8	4053.4	1332.6	4128.7	33
34	.5667	1204.9	3906.3	1246.7	3980.0	1289.5	4054.6	1333.3	4130.0	34
35	.5833	1205.6	3907.5	1247.4	3981.2	1290.2	4055.9	1334.1	4131.5	35
36	.6000	1206.2	3908.7	1248.1	3982.4	1290.9	4057.1	1334.8	4132.6	36
37	.6167	1206.9	3909.9	1248.8	3983.7	1291.7	4058.4	1335.6	4133.9	37
38	.6333	1207.6	3911.2	1249.5	3984.9	1292.4	4059.6	1336.3	4135.1	38
39	.6500	1208.3	3912.4	1250.2	3986.1	1293.1	4060.9	1337.1	4136.4	39
40	.6667	1209.0	3913.6	1250.9	3987.4	1293.8	4062.1	1337.8	4137.7	40
41	.6833	1209.7	3914.9	1251.6	3988.7	1294.6	4063.4	1338.5	4139.0	41
42	.7000	1210.3	3916.1	1252.3	3989.9	1295.3	4064.6	1339.2	4140.2	42
43	.7167	1211.0	3917.3	1253.0	3991.1	1296.0	4065.9	1340.0	4141.5	43
44	.7333	1211.7	3918.5	1253.7	3992.3	1296.7	4067.1	1340.7	4142.7	44
45	.7500	1212.4	3919.8	1254.4	3993.6	1297.5	4068.4	1341.5	4144.0	45
46	.7667	1213.1	3921.0	1255.1	3994.8	1298.2	4069.6	1342.2	4145.3	46
47	.7833	1213.8	3922.2	1255.8	3996.0	1298.9	4070.9	1343.0	4146.6	47
48	.8000	1214.5	3923.4	1256.5	3997.3	1299.6	4072.1	1343.7	4147.8	48
49	.8167	1215.2	3924.7	1257.2	3998.6	1300.4	4073.4	1344.5	4149.1	49
50	.8333	1215.9	3925.9	1257.9	3999.8	1301.1	4074.6	1345.2	4150.4	50
51	.8500	1216.6	2927.1	1258.6	4001.0	1301.9	4075.9	1346.0	4151.7	51
52	.8667	1217.3	3928.3	1259.3	4002.2	1302.6	4077.1	1346.7	4152.9	52
53	.8833	1218.0	3929.6	1260.0	4003.4	1303.3	4078.4	1347.5	4154.2	53
54	.9000	1218.7	3930.8	1260.7	4004.7	1304.0	4079.6	1348.2	4155.4	54
55	.9167	1219.4	3932.0	1261.4	4006.0	1304.8	4080.9	1349.0	4156.7	55
56	.9333	1220.1	3933.2	1262.1	4007.2	1305.5	4082.1	1349.7	4158.0	56
57	9500	1220.8	3934.4	1262.8	4008.5	1306.2	4083.4	1350.5	4159.3	57
58	.9667	1221.5	3935.7	1263.5	4009.7	1306.9	4084.6	1351.2	4160.5	58
59	.9833	1222.2	3936.9	1264.3	4010.9	1307.7	4085.9	1352.0	4161.8	59

Use 100′ Chords up to 8° Curves
Use 50′ Chords up to 16° Curves
Use 25′ Chords up to 32° Curves
Use 10′ Chords above 32° Curves

Minutes	Dec. of Degree	72° Ext.	72° Tan.	73° Ext.	73° Tan.	74° Ext.	74° Tan.	75° Ext.	75° Tan.	Minutes
0	.0000	1352.7	4163.1	1398.1	4240.0	1444.7	4317.8	1492.5	4396.7	0
1	.0167	1353.5	4164.4	1398.9	4241.3	1445.5	4319.2	1493.3	4398.1	1
2	.0333	1354.2	4165.6	1399.6	4242.6	1446.2	4320.5	1494.1	4399.4	2
3	.0500	1355.0	4166.9	1400.4	4243.9	1447.0	4321.8	1494.9	4400.8	3
4	.0667	1355.7	4168.2	1401.2	4245.1	1447.8	4323.1	1495.7	4402.1	4
5	.0833	1356.5	4169.5	1402.0	4246.4	1448.6	4324.4	1496.5	4403.4	5
6	.1000	1357.2	4170.7	1402.7	4247.7	1449.4	4325.7	1497.3	4404.7	6
7	.1167	1358.0	4172.0	1403.5	4249.0	1450.2	4327.0	1498.2	4406.1	7
8	.1333	1358.7	4173.3	1404.2	4250.3	1451.0	4328.3	1499.0	4407.4	8
9	.1500	1359.5	4174.5	1405.0	4251.6	1451.8	4329.6	1499.8	4408.7	9
10	.1667	1360.2	4175.8	1405.8	4252.9	1452.6	4330.9	1500.6	4410.0	10
11	.1833	1361.0	4177.1	1406.6	4254.2	1453.4	4332.3	1501.4	4411.4	11
12	.2000	1361.7	4178.4	1407.3	4255.5	1454.1	4333.6	1502.2	4412.7	12
13	.2167	1362.5	4179.7	1408.1	4256.8	1454.9	4334.9	1503.0	4414.0	13
14	.2333	1363.2	4181.0	1408.8	4258.1	1455.7	4336.2	1503.8	4415.3	14
15	.2500	1364.0	4182.3	1409.6	4259.4	1456.5	4337.5	1504.6	4416.6	15
16	.2667	1364.7	4183.5	1410.4	4260.7	1457.3	4338.8	1505.4	4418.0	16
17	.2833	1365.5	4184.8	1411.2	4262.0	1458.1	4340.1	1506.2	4419.4	17
18	.3000	1366.2	4186.1	1411.9	4263.2	1458.9	4341.4	1507.0	4420.7	18
19	.3167	1367.0	4187.4	1412.7	4264.5	1459.7	4342.7	1507.9	4422.0	19
20	.3333	1367.7	4188.6	1413.5	4265.8	1460.5	4344.0	1508.7	4423.3	20
21	.3500	1368.5	4189.9	1414.3	4267.1	1461.3	4345.4	1509.5	4424.6	21
22	.3667	1369.2	4191.2	1415.1	4268.4	1462.0	4346.7	1510.3	4426.0	22
23	.3833	1370.0	4192.5	1415.9	4269.7	1462.8	4348.0	1511.2	4427.3	23
24	.4000	1370.7	4193.7	1416.6	4271.0	1463.6	4349.3	1512.0	4428.6	24
25	.4167	1371.5	4195.0	1417.4	4272.3	1464.4	4350.6	1512.8	4430.0	25
26	.4333	1372.2	4196.3	1418.2	4273.6	1465.2	4351.9	1513.6	4431.3	26
27	.4500	1373.0	4197.6	1419.0	4274.9	1466.0	4353.2	1514.5	4432.7	27
28	.4667	1373.7	4198.8	1419.7	4276.2	1466.8	4354.5	1515.3	4434.0	28
29	.4833	1374.5	4200.1	1420.5	4277.5	1467.6	4355.8	1516.1	4435.3	29
30	.5000	1375.2	4201.4	1421.3	4278.8	1468.4	4357.1	1516.9	4436.6	30
31	.5167	1376.0	4202.7	1422.1	4280.1	1469.2	4358.5	1517.7	4438.0	31
32	.5333	1376.7	4204.0	1422.9	4281.4	1469.9	4359.8	1518.5	4439.3	32
33	.5500	1377.5	4205.3	1423.7	4282.7	1470.7	4361.1	1519.4	4440.7	33
34	.5667	1378.2	4206.5	1424.4	4284.0	1471.5	4362.4	1520.2	4442.0	34
35	.5833	1379.0	4207.8	1425.2	4285.3	1472.3	4363.8	1521.0	4443.3	35
36	.6000	1379.7	4209.1	1426.0	4286.6	1473.1	4365.1	1521.8	4444.6	36
37	.6167	1380.5	4210.4	1426.8	4287.9	1473.9	4366.4	1522.7	4446.0	37
38	.6333	1381.2	4211.7	1427.5	4289.2	1474.7	4367.7	1523.5	4447.3	38
39	.6500	1382.0	4213.0	1428.3	4290.5	1475.6	4369.0	1524.3	4448.7	39
40	.6667	1382.8	4214.3	1429.1	4291.8	1476.4	4370.3	1525.1	4450.0	40
41	.6833	1383.6	4215.6	1429.9	4293.1	1477.2	4371.7	1525.9	4451.4	41
42	.7000	1384.3	4216.8	1430.7	4294.4	1478.0	4373.0	1526.7	4452.7	42
43	.7167	1385.1	4218.1	1431.5	4295.7	1478.8	4374.3	1527.6	4454.0	43
44	.7333	1385.8	4219.4	1432.2	4297.0	1479.6	4375.6	1528.4	4455.3	44
45	.7500	1386.6	4220.7	1433.0	4298.3	1480.4	4377.0	1529.2	4456.7	45
46	.7667	1387.4	4222.0	1433.8	4299.6	1481.2	4378.3	1530.0	4458.0	46
47	.7833	1388.2	4223.3	1434.6	4300.9	1482.0	4379.6	1530.9	4459.4	47
48	.8000	1388.9	4224.5	1435.3	4302.2	1482.8	4380.9	1531.7	4460.7	48
49	.8167	1389.7	4225.8	1436.1	4303.5	1483.6	4382.2	1532.5	4462.1	49
50	.8333	1390.4	4227.1	1436.9	4304.8	1484.4	4383.5	1533.3	4463.4	50
51	.8500	1391.2	4228.4	1437.7	4306.1	1485.2	4384.9	1534.1	4464.7	51
52	.8667	1392.0	4229.7	1438.5	4307.4	1486.0	4386.2	1534.9	4466.0	52
53	.8833	1392.8	4231.0	1439.3	4308.7	1486.9	4387.5	1535.8	4467.4	53
54	.9000	1393.5	4232.3	1440.0	4310.0	1487.7	4388.8	1536.6	4468.7	54
55	.9167	1394.3	4233.6	1440.8	4311.3	1488.5	4390.2	1537.4	4470.1	55
56	.9333	1395.0	4234.8	1441.6	4312.6	1489.3	4391.5	1538.2	4471.4	56
57	.9500	1395.8	4236.1	1442.4	4313.9	1490.1	4392.8	1539.1	4472.7	57
58	.9667	1396.6	4237.4	1443.1	4315.2	1490.9	4394.1	1539.9	4474.1	58
59	.9833	1397.4	4238.7	1443.9	4316.5	1491.7	4395.4	1540.7	4475.4	59

Use 100′ Chords up to 8° Curves Use 25′ Chords up to 32° Curves
Use 50′ Chords up to 16° Curves Use 10′ Chords above 32° Curves

Minutes	Dec. of Degree	76°		77°		78°		79°		Minutes
		Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	
0	.0000	1541.5	4476.7	1591.7	4557.8	1643.1	4640.0	1696.0	4723.4	0
1	.0167	1542.4	4478.1	1592.6	4559.2	1644.0	4641.4	1696.9	4724.8	1
2	.0333	1543.2	4479.4	1593.4	4560.5	1644.8	4642.8	1697.7	4726.2	2
3	.0500	1544.1	4480.8	1594.3	4561.9	1645.7	4644.2	1698.6	4727.6	3
4	.0667	1544.9	4482.1	1595.1	4563.3	1646.6	4645.6	1699.5	4729.0	4
5	.0833	1545.7	4483.5	1596.0	4564.7	1647.5	4647.0	1700.4	4730.4	5
6	.1000	1546.5	4484.8	1596.8	4566.0	1648.3	4648.3	1701.3	4731.8	6
7	.1167	1547.4	4486.2	1597.7	4567.4	1649.2	4649.7	1702.2	4733.3	7
8	.1333	1548.2	4487.5	1598.5	4568.7	1650.1	4651.1	1703.1	4734.7	8
9	.1500	1549.1	4488.9	1599.4	4570.1	1651.0	4652.5	1704.0	4736.1	9
10	.1667	1549.9	4490.2	1600.2	4571.5	1651.8	4653.9	1704.9	4737.5	10
11	.1833	1550.7	4491.6	1601.1	4572.9	1652.7	4655.3	1705.8	4738.9	11
12	.2000	1551.5	4492.9	1601.9	4574.2	1653.6	4656.7	1706.6	4740.3	12
13	.2167	1552.4	4494.3	1602.8	4575.6	1654.5	4658.1	1707.5	4741.7	13
14	.2333	1553.2	4495.6	1603.6	4576.9	1655.3	4659.4	1708.4	4743.1	14
15	.2500	1554.1	4497.0	1604.5	4578.3	1656.2	4660.8	1709.3	4744.5	15
16	.2667	1554.9	4498.3	1605.3	4579.7	1657.1	4662.2	1710.2	4745.9	16
17	.2833	1555.7	4499.7	1606.2	4581.1	1658.0	4663.6	1711.1	4747.3	17
18	.3000	1556.5	4501.0	1607.0	4582.4	1658.8	4665.0	1712.0	4748.7	18
19	.3167	1557.4	4502.4	1607.9	4583.8	1659.7	4666.4	1712.9	4750.1	19
20	.3333	1558.2	4503.7	1608.7	4585.1	1660.6	4667.7	1713.8	4751.5	20
21	.3500	1559.1	4505.0	1609.6	4586.5	1661.5	4669.1	1714.7	4752.9	21
22	.3667	1559.9	4506.3	1610.4	4587.9	1662.3	4670.5	1715.6	4754.3	22
23	.3833	1560.7	4507.7	1611.3	4589.3	1663.2	4671.9	1716.5	4755.7	23
24	.4000	1561.5	4509.0	1612.1	4590.6	1664.1	4673.3	1717.4	4757.1	24
25	.4167	1562.4	4510.4	1613.0	4592.0	1665.0	4674.7	1718.3	4758.6	25
26	.4333	1563.2	4511.7	1613.8	4593.3	1665.8	4676.0	1719.2	4760.0	26
27	.4500	1564.1	4513.1	1614.7	4594.7	1666.7	4677.4	1720.1	4761.4	27
28	.4667	1564.9	4514.4	1615.5	4596.0	1667.6	4678.8	1721.0	4762.8	28
29	.4833	1565.7	4515.8	1616.4	4597.4	1668.5	4680.2	1721.9	4764.2	29
30	.5000	1566.5	4517.1	1617.3	4598.8	1669.3	4681.6	1722.8	4765.6	30
31	.5167	1567.4	4518.5	1618.2	4600.2	1670.2	4683.0	1723.7	4767.0	31
32	.5333	1568.2	4519.8	1619.0	4601.5	1671.1	4684.4	1724.6	4768.4	32
33	.5500	1569.1	4521.1	1619.9	4602.9	1672.0	4685.8	1725.5	4769.8	33
34	.5667	1569.9	4522.5	1620.7	4604.3	1672.8	4687.2	1726.4	4771.2	34
35	.5833	1570.7	4523.9	1621.6	4605.7	1673.7	4688.6	1727.3	4772.7	35
36	.6000	1571.5	4525.3	1622.4	4607.0	1674.6	4689.9	1728.2	4774.1	36
37	.6167	1572.4	4526.7	1623.3	4608.4	1675.5	4691.3	1729.1	4775.5	37
38	.6333	1573.2	4528.0	1624.1	4609.8	1676.3	4692.7	1730.0	4776.9	38
39	.6500	1574.0	4529.4	1625.0	4611.2	1677.3	4694.1	1731.0	4778.3	39
40	.6667	1574.8	4530.7	1625.9	4612.5	1678.2	4695.5	1731.9	4779.7	40
41	.6833	1575.6	4532.1	1626.8	4613.9	1679.1	4696.9	1732.8	4781.1	41
42	.7000	1576.4	4533.4	1627.6	4615.3	1679.9	4698.3	1733.7	4782.6	42
43	.7167	1577.3	4534.8	1628.5	4616.7	1680.8	4699.7	1734.6	4784.0	43
44	.7333	1578.1	4536.1	1629.3	4618.0	1681.7	4701.1	1735.5	4785.4	44
45	.7500	1579.0	4537.5	1630.2	4619.4	1682.6	4702.5	1736.4	4786.8	45
46	.7667	1579.8	4538.8	1631.0	4620.8	1683.5	4703.9	1737.3	4788.2	46
47	.7833	1580.7	4540.2	1631.9	4622.2	1684.4	4705.3	1738.2	4789.6	47
48	.8000	1581.5	4541.5	1632.7	4623.5	1685.3	4706.7	1739.1	4791.0	48
49	.8167	1582.4	4542.9	1633.6	4624.9	1686.2	4708.1	1740.0	4792.5	49
50	.8333	1583.2	4544.2	1634.5	4626.3	1687.1	4709.5	1740.9	4793.9	50
51	.8500	1584.1	4545.6	1635.4	4627.7	1688.0	4710.9	1741.8	4795.3	51
52	.8667	1584.9	4547.0	1636.2	4629.0	1688.8	4712.2	1742.7	4796.7	52
53	.8833	1585.8	4548.4	1637.1	4630.4	1689.7	4713.6	1743.6	4798.1	53
54	.9000	1586.6	4549.7	1637.9	4631.8	1690.6	4715.0	1744.5	4799.5	54
55	.9167	1587.5	4551.1	1638.8	4633.2	1691.5	4716.4	1745.4	4801.0	55
56	.9333	1588.3	4552.4	1639.6	4634.5	1692.4	4717.8	1746.3	4802.4	56
57	.9500	1589.2	4553.8	1640.5	4635.9	1693.3	4719.2	1747.2	4803.8	57
58	.9667	1590.0	4555.1	1641.3	4637.3	1694.2	4720.6	1748.1	4805.2	58
59	.9833	1590.9	4556.5	1642.2	4638.7	1695.1	4722.0	1749.1	4806.6	59

Use 100′ Chords up to 8° Curves
Use 50′ Chords up to 16° Curves
Use 25′ Chords up to 32° Curves
Use 10′ Chords above 32° Curves

Minutes	Dec. of Degree	80° Ext.	80° Tan.	81° Ext.	81° Tan.	82° Ext.	82° Tan.	83° Ext.	83° Tan.
0	.0000	1750.0	4808.0	1805.5	4893.9	1862.3	4981.0	1920.6	5069.4
1	.0167	1750.9	4809.5	1806.4	4895.4	1863.3	4982.5	1921.6	5070.9
2	.0333	1751.8	4810.9	1807.3	4896.8	1864.2	4983.9	1922.6	5072.4
3	.0500	1752.8	4812.3	1808.3	4898.3	1865.2	4985.4	1923.6	5073.9
4	.0667	1753.7	4813.7	1809.2	4899.7	1866.1	4986.8	1924.6	5075.4
5	.0833	1754.6	4815.2	1810.2	4901.2	1867.1	4988.3	1925.6	5076.9
6	.1000	1755.5	4816.6	1811.1	4902.6	1868.1	4989.8	1926.5	5078.4
7	.1167	1756.5	4818.0	1812.1	4904.0	1869.1	4991.3	1927.5	5079.9
8	.1333	1757.4	4819.4	1813.0	4905.4	1870.0	4992.7	1928.5	5081.4
9	.1500	1758.3	4820.9	1814.0	4906.9	1871.0	4994.2	1929.5	5082.9
10	.1667	1759.2	4822.3	1814.9	4908.3	1871.9	4995.7	1930.5	5084.4
11	.1833	1760.1	4823.7	1815.9	4909.8	1872.9	4997.2	1931.5	5085.9
12	.2000	1761.0	4825.1	1816.8	4911.2	1873.9	4998.6	1932.4	5087.3
13	.2167	1762.0	4826.6	1817.7	4912.7	1874.9	5000.1	1933.4	5088.8
14	.2333	1762.9	4828.0	1818.6	4914.1	1875.8	5001.5	1934.4	5090.3
15	.2500	1763.8	4829.4	1819.6	4915.5	1876.8	5003.0	1935.4	5091.8
16	.2667	1764.7	4830.8	1820.5	4917.0	1877.7	5004.5	1936.4	5093.3
17	.2833	1765.7	4832.3	1821.5	4918.5	1878.7	5006.0	1937.4	5094.8
18	.3000	1766.6	4833.7	1822.4	4919.9	1879.7	5007.4	1938.4	5096.3
19	.3167	1767.5	4835.1	1823.3	4921.4	1880.7	5008.9	1939.4	5097.8
20	.3333	1768.4	4836.5	1824.2	4922.8	1881.6	5010.3	1940.4	5099.3
21	.3500	1769.3	4838.0	1825.2	4924.3	1882.6	5011.8	1941.4	5100.8
22	.3667	1770.2	4839.4	1826.1	4925.7	1883.5	5013.3	1942.4	5102.3
23	.3833	1771.2	4840.8	1827.1	4927.2	1884.5	5014.8	1943.4	5103.8
24	.4000	1772.1	4842.2	1828.0	4928.6	1885.5	5016.2	1944.4	5105.2
25	.4167	1773.0	4843.7	1829.0	4930.1	1886.5	5017.7	1945.4	5106.7
26	.4333	1773.9	4845.1	1829.9	4931.5	1887.4	5019.2	1946.4	5108.2
27	.4500	1774.9	4846.5	1830.9	4933.0	1888.4	5020.7	1947.4	5109.7
28	.4667	1775.8	4847 9	1831.8	4934.4	1889.3	5022.1	1948.4	5111.2
29	.4833	1776.7	4849.4	1832.8	4935.8	1890.3	5023.6	1949.4	5112.7
30	.5000	1777.6	4850.8	1833.7	4937.2	1891.3	5025.0	1950.4	5114.2
31	.5167	1778.5	4852.3	1834.7	4938.7	1892.3	5026.5	1951.4	5115.7
32	.5333	1779.4	4853.7	1835.6	4940.2	1893.2	5028.0	1952.4	5117.2
33	.5500	1780.4	4855.1	1836.6	4941.7	1894.2	5029.5	1953.4	5118.7
34	.5667	1781.3	4856.5	1837.5	4943.1	1895.1	5031.0	1954.4	5120.2
35	.5833	1782.2	4858.0	1838.5	4944.6	1896.1	5032.5	1955.4	5121.7
36	.6000	1783.1	4859.4	1839.4	4946.0	1897.1	5033.9	1956.4	5123.2
37	.6167	1784.1	4860.9	1840.4	4947.5	1898.1	5035.4	1957.4	5124.7
38	.6333	1785.0	4862.3	1841.3	4948.9	1899.0	5036.9	1958.4	5126.2
39	.6500	1785.9	4863.7	1842.3	4950.4	1900.0	5038.4	1959.4	5127.7
40	.6667	1786.8	4865.1	1843.2	4951.8	1901.0	5039.8	1960.4	5129.2
41	.6833	1787.7	4866.6	1844.2	4953.3	1902.0	5041.3	1961.4	5130.7
42	.7000	1788.6	4868.0	1845.1	4954.7	1902.9	5042.8	1962.4	5132.2
43	.7167	1789.6	4869.5	1846.1	4956.2	1903.9	5044.3	1963.4	5133.7
44	.7333	1790.5	4870.9	1847.0	4957.6	1904.9	5045.8	1964.4	5135.2
45	.7500	1791.5	4872.4	1848.0	4959.1	1905.9	5047.3	1965.4	5136.7
46	.7667	1792.4	4873.8	1848.9	4960.6	1906.9	5048.7	1966.4	5138.2
47	.7833	1793.4	4875.2	1849.9	4962.1	1907.9	5050.2	1967.4	5139.7
48	.8000	1794.3	4876.6	1850.8	4963.5	1908.8	5051.7	1968.4	5141.2
49	.8167	1795.3	4878.1	1851.8	4965.0	1909.8	5053.2	1969.4	5142.8
50	.8333	1796.2	4879.5	1852.7	4966.4	1910.8	5054.6	1970.4	5144.3
51	.8500	1797.1	4880.9	1853.7	4967.9	1911.8	5056.1	1971.4	5145.8
52	.8667	1798.0	4882.4	1854.6	4969.3	1912.8	5057.6	1972.4	5147.3
53	.8833	1799.0	4883.9	1855.6	4970.8	1913 8	5059.1	1973.4	5148.8
54	.9000	1799.9	4885.3	1856.5	4972.2	1914.7	5060.6	1974.4	5150.3
55	.9167	1800.9	4886.7	1857.5	4973.7	1915.7	5062.1	1975.4	5151.8
56	.9333	1801.8	4888.1	1858.4	4975.1	1916.7	5063.5	1976.4	5153.3
57	.9500	1802.8	4889.6	1859.4	4976.6	1917.7	5065.0	1977.4	5154.8
58	.9667	1803.7	4891.0	1860.3	4978.0	1918.7	5066.5	1978.4	5156.3
59	.9833	1804.6	4892.5	1861.3	4979.5	1919.7	5068.0	1979.4	5157.8

Use 100′ Chords up to 8° Curves Use 25′ Chords up to 32° Curves
Use 50′ Chords up to 16° Curves Use 10′ Chords above 32° Curves

Minutes	Dec. of Degree	84° Ext.	84° Tan.	85° Ext.	85° Tan.	86° Ext.	86° Tan.	87° Ext.	87° Tan.	Minutes
0	.0000	1980.5	5159.3	2041.8	5250.6	2104.8	5343.3	2169.5	5437.5	0
1	.0167	1981.5	5160.8	2042.9	5252.1	2105.9	5344.9	2170.6	5439.1	1
2	.0333	1982.5	5162.3	2043.9	5253.6	2106.9	5346.4	2171.6	5440.7	2
3	.0500	1983.5	5163.8	2045.0	5255.2	2108.0	5348.0	2172.7	5442.3	3
4	.0667	1984.5	5165.3	2046.0	5256.7	2109.1	5349.5	2173.8	5443.9	4
5	.0833	1985.6	5166.9	2047.0	5258.3	2110.1	5351.1	2174.9	5445.5	5
6	.1000	1986.6	5168.4	2048.0	5259.8	2111.2	5352.7	2176.0	5447.1	6
7	.1167	1987.6	5169.9	2049.1	5261.4	2112.3	5354.3	2177.1	5448.7	7
8	.1333	1988.6	5171.4	2050.1	5262.9	2113.4	5355.8	2178.2	5450.3	8
9	.1500	1989.6	5172.9	2051.2	5264.5	2114.5	5357.4	2179.3	5451.9	9
10	.1667	1990.6	5174.4	2052.2	5266.0	2115.5	5358.9	2180.4	5453.4	10
11	.1833	1991.7	5175.9	2053.2	5267.5	2116.6	5360.5	2181.5	5455.0	11
12	.2000	1992.7	5177.5	2054.2	5269.0	2117.6	5362.0	2182.5	5456.6	12
13	.2167	1993.7	5179.0	2055.3	5270.6	2118.7	5363.6	2183.6	5458.2	13
14	.2333	1994.7	5180.5	2056.3	5272.1	2119.8	5365.2	2184.7	5459.8	14
15	.2500	1995.7	5182.0	2057.4	5273.7	2120.9	5366.8	2185.8	5461.4	15
16	.2667	1996.7	5183.5	2058.4	5275.2	2121.9	5368.3	2186.9	5463.0	16
17	.2833	1997.8	5185.0	2059.5	5276.8	2123.0	5369.9	2188.0	5464.6	17
18	.3000	1998.8	5186.6	2060.5	5278.3	2124.1	5371.4	2189.1	5466.2	18
19	.3167	1999.8	5188.0	2061.6	5279.9	2125.2	5373.0	2190.2	5467.8	19
20	.3333	2000.8	5189.6	2062.6	5281.4	2126.2	5374.6	2191.3	5469.4	20
21	.3500	2001.8	5191.0	2063.7	5282.9	2127.3	5376.2	2192.4	5471.0	21
22	.3667	2002.8	5192.6	2064.7	5284.4	2128.3	5377.7	2193.5	5472.5	22
23	.3833	2003.9	5194.0	2065.8	5286.0	2129.4	5379.3	2194.6	5474.1	23
24	.4000	2004.9	5195.6	2066.8	5287.5	2130.5	5380.8	2195.7	5475.7	24
25	.4167	2005.9	5197.2	2067.9	5289.1	2131.6	5382.4	2196.8	5477.3	25
26	.4333	2006.9	5198.7	2068.9	5290.6	2132.6	5383.9	2197.9	5478.9	26
27	.4500	2007.9	5200.2	2070.0	5292.2	2133.7	5385.5	2199.0	5480.5	27
28	.4667	2008.9	5201.7	2071.0	5293.7	2134.8	5387.1	2200.1	5482.1	28
29	.4833	2010.0	5203.2	2072.1	5295.2	2135.9	5388.7	2201.2	5483.7	29
30	.5000	2011.0	5204.7	2073.1	5296.7	2136.9	5390.2	2202.3	5485.3	30
31	.5167	2012.0	5206.3	2074.2	5298.3	2138.0	5391.8	2203.4	5486.9	31
32	.5333	2013.0	5207.8	2075.2	5299.8	2139.0	5393.4	2204.5	5488.5	32
33	.5500	2014.0	5209.3	2076.3	5301.4	2140.1	5395.0	2205.6	5490.1	33
34	.5667	2015.0	5210.8	2077.3	5302.9	2141.2	5396.5	2206.8	5491.7	34
35	.5833	2016.0	5212.4	2078.4	5304.5	2142.3	5398.1	2207.9	5493.3	35
36	.6000	2017.0	5213.9	2079.4	5306.1	2143.3	5399.7	2209.0	5494.9	36
37	.6167	2018.0	5215.4	2080.5	5307.7	2144.4	5401.3	2210.1	5496.5	37
38	.6333	2019.1	5216.9	2081.5	5309.2	2145.5	5402.8	2211.2	5498.1	38
39	.6500	2020.1	5218.4	2082.6	5310.8	2146.6	5404.4	2212.3	5499.7	39
40	.6667	2021.2	5220.0	2083.7	5312.3	2147.7	5406.0	2213.4	5501.3	40
41	.6833	2022.2	5221.6	2084.8	5313.9	2148.8	5407.6	2214.5	5502.9	41
42	.7000	2023.2	5223.1	2085.8	5315.4	2149.8	5409.1	2215.6	5504.5	42
43	.7167	2024.3	5224.6	2086.9	5317.0	2150.9	5410.7	2216.7	5506.1	43
44	.7333	2025.3	5226.1	2087.9	5318.5	2152.0	5412.3	2217.8	5507.7	44
45	.7500	2026.4	5227.7	2089.0	5320.1	2153.1	5413.9	2218.9	5509.3	45
46	.7667	2027.4	5229.2	2090.0	5321.6	2154.2	5415.4	2220.0	5510.9	46
47	.7833	2028.4	5230.7	2091.1	5323.2	2155.3	5417.0	2221.2	5512.5	47
48	.8000	2029.4	5232.2	2092.1	5324.7	2156.4	5418.6	2222.3	5514.1	48
49	.8167	2030.5	5233.8	2093.2	5326.3	2157.5	5420.2	2223.4	5515.7	49
50	.8333	2031.5	5235.3	2094.2	5327.8	2158.6	5421.8	2224.5	5517.3	50
51	.8500	2032.6	5236.8	2095.3	5329.4	2159.7	5423.4	2225.6	5518.9	51
52	.8667	2033.6	5238.3	2096.3	5330.9	2160.7	5424.9	2226.7	5520.5	52
53	.8833	2034.6	5239.9	2097.4	5332.5	2161.8	5426.5	2227.9	5522.1	53
54	.9000	2035.6	5241.4	2098.4	5334.0	2162.9	5428.1	2228.9	5523.7	54
55	.9167	2036.7	5243.0	2099.5	5335.6	2164.0	5429.7	2230.0	5525.3	55
56	.9333	2037.7	5244.5	2100.6	5337.1	2165.1	5431.2	2231.1	5526.9	56
57	.9500	2038.7	5246.0	2101.7	5338.7	2166.2	5432.8	2232.2	5528.5	57
58	.9667	2039.8	5247.5	2102.7	5340.2	2167.3	5434.4	2233.3	5530.1	58
59	.9833	2040.8	5249.1	2103.8	5341.8	2168.4	5436.0	2234.5	5531.7	59

Use 100′ Chords up to 8° Curves Use 25′ Chords up to 32° Curves
Use 50′ Chords up to 16° Curves Use 10′ Chords above 32° Curves

Minutes	Dec. of Degree	88°		89°		90°		91°	
		Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	Ext.	Tan.
0	.0000	2235.6	5533.3	2303.6	5630.8	2373.4	5730.0	2445.1	5830
1	.0167	2236.7	5535.0	2304.7	5632.5	2374.6	5731.7	2446.3	5832
2	.0333	2237.8	5536.6	2305.6	5634.1	2375.8	5733.3	2447.5	5834
3	.0500	2238.9	5538.2	2307.2	5635.8	2377.0	5735.0	2448.8	5836
4	.0667	2240.1	5539.8	2308.1	5637.4	2378.2	5736.7	2450.0	5837
5	.0833	2241.2	5541.5	2309.4	5639.1	2379.4	5738.4	2451.2	5839
6	.1000	2242.3	5543.1	2310.5	5640.7	2380.5	5740.0	2452.4	5841
7	.1167	2243.5	5544.7	2311.6	5642.4	2381.7	5741.7	2453.6	5842.
8	.1333	2244.6	5546.3	2312.8	5644.0	2382.9	5743.4	2454.8	5844.
9	.1500	2245.7	5547.9	2314.0	5645.7	2384.1	5745.1	2456.0	5846.
10	.1667	2246.8	5549.5	2315.1	5647.3	2385.3	5746.7	2457.2	5847.
11	.1833	2248.0	5551.2	2316.3	5649.0	2386.4	5748.4	2458.5	5849.
12	.2000	2249.1	5552.8	2317.4	5650.6	2387.6	5750.0	2459.7	5851.
13	.2167	2250.2	5554.4	2318.6	5652.3	2388.8	5751.7	2460.9	5853.
14	.2333	2251.3	5556.0	2319.7	5653.9	2390.0	5753.4	2462.1	5854.
15	.2500	2252.5	5557.6	2320.9	5655.5	2391.2	5755.1	2463.3	5856.
16	.2667	2253.6	5559.2	2322.0	5657.1	2392.4	5756.7	2464.5	5858.
17	.2833	2254.7	5560.9	2323.2	5658.8	2393.5	5758.4	2465.8	5859.
18	.3000	2255.8	5562.5	2324.3	5660.4	2394.7	5760.1	2467.0	5861.
19	.3167	2257.0	5564.1	2325.6	5662.1	2395.9	5761.8	2468.2	5863.
20	.3333	2258.1	5565.7	2326.7	5663.7	2397.1	5763.4	2469.4	5864.
21	.3500	2259.3	5567.3	2327.9	5665.4	2398.3	5765.1	2470.6	5866.
22	.3667	2260.4	5568.9	2329.0	5667.0	2399.5	5766.8	2471.9	5868.
23	.3833	2261.5	5570.6	2330.1	5668.7	2400.7	5768.5	2473.1	5870.
24	.4000	2262.7	5572.2	2331.3	5670.3	2401.9	5770.1	2474.3	5871.
25	.4167	2263.8	5573.8	2332.5	5672.0	2403.1	5771.8	2475.5	5873.
26	.4333	2264.9	5575.4	2333.7	5673.6	2404.3	5773.5	2476.7	5875.
27	.4500	2266.0	5577.0	2334.8	5675.3	2405.5	5775.2	2478.0	5876.
28	.4667	2267.2	5578.6	2336.0	5676.9	2406.6	5776.9	2479.2	5878.
29	.4833	2268.4	5580.3	2337.1	5678.6	2407.8	5778.6	2480.4	5880.
30	.5000	2269.5	5581.9	2338.3	5680.2	2409.0	5780.2	2481.6	5882.
31	.5167	2270.6	5583.5	2339.5	5681.9	2410.2	5781.9	2482.9	5883.
32	.5333	2271.7	5585.1	2340.7	5683.5	2411.4	5783.6	2484.1	5885.
33	.5500	2272.8	5586.8	2341.9	5685.2	2412.6	5785.3	2485.3	5887.
34	.5667	2273.9	5588.4	2343.0	5686.8	2413.8	5787.0	2486.5	5888.
35	.5833	2275.1	5590.1	2344.1	5688.5	2415.0	5788.7	2487.8	5890.
36	.6000	2276.2	5591.7	2345.3	5690.2	2416.2	5790.3	2489.0	5892.
37	.6167	2277.3	5593.3	2346.5	5691.9	2417.4	5792.0	2490.3	5894.
38	.6333	2278.5	5594.9	2347.7	5693.5	2418.6	5793.7	2491.5	5895.
39	.6500	2279.7	5596.6	2348.9	5695.2	2419.8	5795.4	2492.7	5897.
40	.6667	2280.8	5598.2	2350.0	5696.8	2421.0	5797.1	2493.9	5899.
41	.6833	2281.9	5599.8	2351.2	5698.5	2422.2	5798.8	2495.2	5900.
42	.7000	2283.0	5601.4	2352.3	5700.1	2423.4	5800.4	2496.4	5902.
43	.7167	2284.1	5603.1	2353.5	5701.8	2424.6	5802.1	2497.7	5904.
44	.7333	2285.3	5604.7	2354.7	5703.4	2425.8	5803.8	2498.9	5906.
45	.7500	2286.5	5606.4	2355.8	5705.1	2427.0	5805.5	2500.1	5907.
46	.7667	2287.6	5608.0	2357.0	5706.8	2428.2	5807.2	2501.3	5909.
47	.7833	2288.7	5609.6	2358.1	5708.5	2429.4	5808.9	2502.6	5911.
48	.8000	2289.9	5611.2	2359.3	5710.1	2430.6	5810.6	2503.8	5912.
49	.8167	2291.1	5612.9	2360.5	5711.8	2431.8	5812.3	2505.1	5914.
50	.8333	2292.2	5614.5	2361.7	5713.4	2433.0	5814.0	2506.3	5916.
51	.8500	2293.3	5616.2	2362.9	5715.1	2434.2	5815.7	2507.5	5918.
52	.8667	2294.4	5617.8	2364.0	5716.7	2435.4	5817.3	2508.7	5919.
53	.8833	2295.6	5619.4	2365.1	5718.4	2436.6	5819.0	2510.0	5921.
54	.9000	2296.7	5621.0	2366.3	5720.0	2437.9	5820.7	2511.2	5923.
55	.9167	2297.9	5622.7	2367.5	5721.7	2439.1	5822.4	2512.5	5925
56	.9333	2299.0	5624.3	2368.7	5723.4	2440.3	5824.1	2513.7	5926
57	.9500	2300.2	5625.9	2369.9	5725.1	2441.5	5825.8	2515.0	5928
58	.9667	2301.3	5627.5	2371.0	5726.7	2442.7	5827.5	2516.2	5930
59	.9833	2302.4	5629.2	2372.2	5728.4	2443.9	5829.2	2517.5	5931

Use 100′ Chords up to 8° Curves Use 25′ Chords up to 32° Curves
Use 50′ Chords up to 16° Curves Use 10′ Chords above 32° Curves

Minutes	Dec. of Degree	92°		93°		94°		95°		Minutes
		Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	
0	.0000	2518.7	5933.6	2594.2	6038.2	2671.8	6144.7	2751.5	6253.2	0
1	.0167	2520.0	5935.3	2595.5	6040.0	2673.1	6146.5	2752.9	6255.1	1
2	.0333	2521.2	5937.0	2596.8	6041.7	2674.4	6148.3	2754.2	6256.9	2
3	.0500	2522.4	5938.8	2598.1	6043.5	2675.7	6150.1	2755.6	6258.7	3
4	.0667	2523.6	5940.5	2599.3	6045.2	2677.0	6151.9	2756.9	6260.5	4
5	.0833	2524.9	5942.3	2600.6	6047.0	2678.4	6153.7	2758.3	6262.4	5
6	.1000	2526.1	5944.0	2601.9	6048.7	2679.7	6155.4	2759.6	6264.2	6
7	.1167	2527.4	5945.7	2603.2	6050.5	2681.0	6157.2	2761.0	6266.0	7
8	.1333	2528.6	5947.4	2604.4	6052.2	2682.3	6159.0	2762.3	6267.8	8
9	.1500	2529.9	5949.2	2605.7	6054.0	2683.6	6160.8	2763.7	6269.7	9
10	.1667	2531.1	5950.9	2607.0	6055.8	2684.9	6162.6	2765.0	6271.5	10
11	.1833	2532.4	5952.7	2608.3	6057.5	2686.3	6164.4	2766.4	6273.4	11
12	.2000	2533.6	5954.4	2609.6	6059.3	2687.6	6166.2	2767.7	6275.2	12
13	.2167	2534.9	5956.1	2610.9	6061.1	2688.9	6168.0	2769.1	6277.0	13
14	.2333	2536.1	5957.8	2612.1	6062.8	2690.2	6169.8	2770.4	6278.8	14
15	.2500	2537.4	5959.6	2613.4	6064.6	2691.5	6171.6	2771.8	6280.7	15
16	.2667	2538.6	5961.3	2614.7	6066.4	2692.8	6173.4	2773.1	6282.5	16
17	.2833	2539.9	5963.1	2616.0	6068.2	2694.2	6175.2	2774.5	6284.4	17
18	.3000	2541.1	5964.8	2617.3	6069.9	2695.6	6177.0	2775.8	6286.2	18
19	.3167	2542.4	5966.5	2618.6	6071.7	2696.9	6178.8	2777.2	6288.0	19
20	.3333	2543.6	5968.2	2619.8	6073.4	2698.1	6180.6	2778.5	6289.8	20
21	.3500	2544.9	5970.0	2621.1	6075.2	2699.5	6182.4	2779.9	6291.7	21
22	.3667	2546.1	5971.7	2622.4	6077.0	2700.8	6184.2	2781.2	6293.5	22
23	.3833	2547.4	5973.5	2623.7	6078.8	2702.1	6186.0	2782.6	6295.4	23
24	.4000	2548.6	5975.2	2625.0	6080.5	2703.4	6187.8	2784.0	6297.2	24
25	.4167	2549.9	5977.0	2626.3	6082.3	2704.8	6189.7	2785.4	6299.1	25
26	.4333	2551.2	5978.7	2627.6	6084.1	2706.1	6191.5	2786.7	6300.9	26
27	.4500	2552.5	5980.5	2628.9	6085.9	2707.4	6193.3	2788.1	6302.7	27
28	.4667	2553.7	5982.2	2630.2	6087.6	2708.7	6195.1	2789.4	6304.6	28
29	.4833	2555.0	5983.9	2631.5	6089.4	2710.1	6196.9	2790.8	6306.4	29
30	.5000	2556.2	5985.6	2632.7	6091.2	2711.4	6198.7	2792.1	6308.2	30
31	.5167	2557.5	5987.4	2634.0	6093.0	2712.7	6200.5	2793.5	6310.1	31
32	.5333	2558.7	5989.1	2635.3	6094.7	2714.0	6202.3	2794.9	6311.9	32
33	.5500	2560.0	5990.9	2636.6	6096.5	2715.4	6204.1	2796.3	6313.8	33
34	.5667	2561.2	5992.6	2637.9	6098.3	2716.7	6205.9	2797.6	6315.6	34
35	.5833	2562.5	5994.4	2639.2	6100.1	2718.0	6207.7	2799.0	6317.5	35
36	.6000	2563.8	5996.1	2640.5	6101.8	2719.3	6209.5	2800.3	6319.3	36
37	.6167	2565.1	5997.9	2641.8	6103.6	2720.7	6211.4	2801.7	6321.2	37
38	.6333	2566.3	5999.6	2643.1	6105.4	2722.0	6213.2	2803.1	6323.0	38
39	.6500	2567.6	6001.4	2644.4	6107.2	2723.4	6215.0	2804.5	6324.9	39
40	.6667	2568.8	6003.1	2645.7	6109.0	2724.7	6216.8	2805.8	6326.7	40
41	.6833	2570.1	6004.9	2647.0	6110.8	2726.0	6218.6	2807.2	6328.6	41
42	.7000	2571.3	6006.6	2648.3	6112.5	2727.3	6220.4	2808.6	6330.4	42
43	.7167	2572.6	6008.4	2649.6	6114.3	2728.7	6222.3	2810.0	6332.3	43
44	.7333	2573.9	6010.1	2650.9	6116.1	2730.0	6224.1	2811.3	6334.1	44
45	.7500	2575.2	6011.9	2652.2	6117.9	2731.4	6225.9	2812.7	6336.0	45
46	.7667	2576.4	6013.6	2653.5	6119.7	2732.7	6227.7	2814.1	6337.8	46
47	.7833	2577.7	6015.4	2654.8	6121.5	2734.1	6229.5	2815.5	6339.7	47
48	.8000	2578.9	6017.1	2656.1	6123.2	2735.4	6231.3	2816.8	6341.5	48
49	.8167	2580.2	6018.9	2657.4	6125.0	2736.7	6233.2	2818.2	6343.4	49
50	.8333	2581.5	6020.6	2658.7	6126.8	2738.0	6235.0	2819.6	6345.2	50
51	.8500	2582.8	6022.4	2660.0	6128.6	2739.4	6236.8	2821.0	6347.1	51
52	.8667	2584.0	6024.1	2661.3	6130.4	2740.7	6238.6	2822.3	6349.0	52
53	.8833	2585.3	6025.9	2662.6	6132.2	2742.1	6240.5	2823.7	6350.9	53
54	.9000	2586.6	6027.6	2663.9	6133.9	2743.4	6242.3	2825.1	6352.7	54
55	.9167	2587.9	6029.4	2665.3	6135.7	2744.8	6244.2	2826.5	6354.6	55
56	.9333	2589.1	6031.1	2666.6	6137.5	2746.1	6246.0	2827.8	6356.4	56
	.9500	2590.4	6032.9	2667.9	6139.3	2747.5	6247.8	2829.2	6358.3	57
	.9667	2591.7	6034.6	2669.2	6141.1	2748.8	6249.6	2830.6	6360.1	58
	.9833	2593.0	6036.4	2670.5	6142.9	2750.2	6251.4	2832.0	6362.0	59

Use 100′ Chords up to 8° Curves   Use 25′ Chords up to 32° Curves
Use 50′ Chords up to 16° Curves   Use 10′ Chords above 32° Curves

Minutes	Dec. of Degree	96° Ext.	96° Tan.	97° Ext.	97° Tan.	98° Ext.	98° Tan.	99° Ext.	99° Ta
0	.0000	2833.4	6363.8	2917.5	6476.6	3004.0	6591.6	3092.9	670
1	.0167	2834.8	6365.7	2918.9	6478.5	3005.5	6593.6	3094.4	671
2	.0333	2836.1	6367.5	2920.3	6480.4	3006.9	6595.5	3095.9	671
3	.0500	2837.5	6369.4	2921.8	6482.3	3008.4	6597.5	3097.4	671
4	.0667	2838.9	6371.3	2923.2	6484.2	3009.8	6599.4	3098.9	671
5	.0833	2840.3	6373.2	2924.6	6486.1	3011.3	6601.3	3100.4	671
6	.1000	2841.7	6375.0	2926.0	6488.0	3012.8	6603.2	3101.9	672
7	.1167	2843.1	6376.9	2927.5	6489.9	3014.3	6605.2	3103.4	672
8	.1333	2844.5	6378.7	2928.9	6491.8	3015.7	6607.1	3104.9	672
9	.1500	2845.9	6380.6	2930.3	6493.7	3017.2	6609.1	3106.4	672
10	.1667	2847.2	6382.5	2931.7	6495.6	3018.6	6611.0	3107.9	672
11	.1833	2848.6	6384.4	2933.2	6497.5	3020.1	6613.0	3109.5	673
12	.2000	2850.0	6386.2	2934.6	6499.4	3021.6	6614.9	3111.0	673
13	.2167	2851.4	6388.1	2936.1	6501.3	3023.1	6616.9	3112.5	673
14	.2333	2852.8	6389.9	2937.5	6503.2	3024.5	6618.8	3114.0	673
15	.2500	2854.2	6391.8	2938.9	6505.2	3026.0	6620.8	3115.5	673
16	.2667	2855.6	6393.7	2940.3	6507.1	3027.5	6622.7	3117.0	674
17	.2833	2857.0	6395.6	2941.8	6509.0	3029.0	6624.7	3118.5	674
18	.3000	2858.4	6397.4	2943.2	6510.9	3030.4	6626.6	3120.0	674
19	.3167	2859.8	6399.3	2944.7	6512.8	3031.9	6628.6	3121.5	674
20	.3333	2861.2	6401.2	2946.1	6514.7	3033.3	6630.5	3123.1	674
21	.3500	2862.6	6403.1	2947.5	6516.6	3034.8	6632.5	3124.6	675
22	.3667	2864.0	6404.9	2948.9	6518.5	3036.3	6634.4	3126.1	675
23	.3833	2865.4	6406.8	2950.4	6520.4	3037.8	6636.4	3127.6	675
24	.4000	2866.7	6408.7	2951.8	6522.3	3039.3	6638.3	3129.1	675
25	.4167	2868.1	6410.6	2953.3	6524.3	3040.8	6640.3	3130.7	675
26	.4333	2869.5	6412.4	2954.7	6526.2	3042.2	6642.2	3132.2	676
27	.4500	2870.9	6414.3	2956.2	6528.1	3043.7	6644.2	3133.7	676
28	.4667	2872.3	6416.2	2957.6	6530.0	3045.2	6646.1	3135.2	676
29	.4833	2873.7	6418.1	2959.0	6531.9	3046.7	6648.1	3136.7	676
30	.5000	2875.1	6419.9	2960.4	6533.8	3048.1	6650.0	3138.3	676
31	.5167	2876.5	6421.8	2961.9	6535.8	3049.6	6652.0	3139.8	677
32	.5333	2877.9	6423.7	2963.3	6537.7	3051.1	6653.9	3141.3	677
33	.5500	2879.4	6425.6	2964.8	6539.6	3052.6	6655.9	3142.9	677
34	.5667	2880.8	6427.5	2966.2	6541.5	3054.1	6657.8	3144.4	677
35	.5833	2882.2	6429.4	2967.7	6543.4	3055.6	6659.8	3145.9	677
36	.6000	2883.6	6431.2	2969.1	6545.3	3057.0	6661.7	3147.4	678
37	.6167	2885.0	6433.1	2970.6	6547.3	3058.5	6663.7	3149.0	678
38	.6333	2886.4	6435.0	2972.0	6549.2	3060.0	6665.7	3150.5	678
39	.6500	2887.8	6436.9	2973.5	6551.1	3061.5	6667.7	3152.0	678
40	.6667	2889.2	6438.8	2974.9	6553.0	3063.0	6669.6	3153.5	678
41	.6833	2890.6	6440.7	2976.4	6555.0	3064.5	6671.6	3155.1	679
42	.7000	2892.0	6442.5	2977.8	6556.9	3066.0	6673.5	3156.6	679
43	.7167	2893.4	6444.4	2979.3	6558.8	3067.5	6675.5	3158.2	679
44	.7333	2894.8	6446.3	2980.7	6560.7	3068.9	6677.4	3159.7	679
45	.7500	2896.3	6448.2	2982.2	6562.7	3070.4	6679.4	3161.2	679
46	.7667	2897.7	6450.1	2983.6	6564.6	3071.9	6681.4	3162.7	680
47	.7833	2899.1	6452.0	2985.1	6566.5	3073.4	6683.4	3164.3	680
48	.8000	2900.5	6453.9	2986.5	6568.4	3074.9	6685.3	3165.8	680
49	.8167	2901.9	6455.8	2988.0	6570.4	3076.4	6687.3	3167.4	680
50	.8333	2903.3	6457.6	2989.4	6572.3	3077.9	6689.2	3168.9	680
51	.8500	2904.7	6459.5	2990.9	6574.3	3079.4	6691.2	3170.5	681
52	.8667	2906.1	6461.4	2992.3	6576.2	3080.9	6693.2	3172.0	681
53	.8833	2907.6	6463.3	2993.8	6578.1	3082.4	6695.2	3173.6	681
54	.9000	2909.0	6465.2	2995.2	6580.0	3083.9	6697.1	3175.1	681
55	.9167	2910.4	6467.1	2996.7	6582.0	3085.4	6699.1	3176.6	681
56	.9333	2911.8	6469.0	2998.1	6583.9	3086.9	6701.1	3178.1	682
57	.9500	2913.3	6470.9	2999.6	6585.8	3088.4	6703.2	3179.7	682
58	.9667	2914.7	6472.8	3001.1	6587.7	3089.9	6705.2	3181.2	682
59	.9833	2916.1	6474.7	3002.6	6589.7	3091.4	6707.1	3182.8	682

Jse 100′ Chords up to 8° Curves
Jse 50′ Chords up to 16° Curves
Use 25′ Chords up to 32° Curves
Use 10′ Chords above 32° Curves

Dec. of Degree	100°		Minutes
	Ext.	Tan.	
.0000	3184.3	6828.8	0
.0167	3185.9	6830.8	1
.0333	3187.4	6832.8	2
.0500	3189.0	6834.8	3
.0667	3190.5	6836.8	4
.0833	3192.1	6838.9	5
.1000	3193.6	6840.9	6
.1167	3195.2	6842.9	7
.1333	3196.7	6844.9	8
.1500	3198.3	6847.0	9
.1667	3199.8	6849.0	10
.1833	3201.4	6851.0	11
.2000	3202.9	6853.0	12
.2167	3204.5	6855.1	13
.2333	3206.0	6857.1	14
.2500	3207.6	6859.1	15
.2667	3209.1	6861.1	16
.2833	3210.7	6863.2	17
.3000	3212.2	6865.2	18
.3167	3213.8	6867.2	19
.3333	3215.4	6869.2	20
.3500	3217.0	6871.3	21
.3667	3218.5	6873.3	22
.3833	3220.1	6875.4	23
.4000	3221.6	6877.4	24
.4167	3223.2	6879.4	25
.4333	3224.7	6881.4	26
.4500	3226.3	6883.5	27
.4667	3227.9	6885.5	28
.4833	3229.5	6887.6	29
5000	3231.0	6889.6	30
5167	3232.6	6891.7	31
5333	3234.1	6893.7	32
5500	3235.7	6895.7	33
5667	3237.3	6897.8	34
5833	3238.9	6899.8	35
6000	3240.4	6901.8	36
6167	3242.0	6903.9	37
6333	3243.5	6905.9	38
6500	3245.1	6908.0	39
6667	3246.7	6910.0	40
6833	3248.3	6912.1	41
000	3249.8	6914.1	42
167	3251.4	6916.2	43
333	3253.0	6918.2	44
500	3254.6	6920.3	45
667	3256.2	6922.3	46
833	3257.8	6924.4	47
000	3259.3	6926.4	48
167	3260.9	6928.5	49
333	3262.5	6930.5	50
500	3264.1	6932.6	51
667	3265.7	6934.6	52
833	3267.3	6936.7	53
000	3268.8	6938.7	54
167	3270.4	6940.8	55
333	3272.0	6942.8	56
500	3273.6	6944.9	57
667	3275.2	6946.9	58
833	3276.8	6949.0	59

Use 100′ Chords up to 8° Curves
Use 50′ Chords up to 16° Curves
Use 25′ Chords up to 32° Curves
Use 10′ Chords above 32° Curves

Minutes	101°		102°		103°		104°		105°		Minutes
	Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	
0	3278.3	6951.0	3375.1	7076.0	3474.6	7203.6	3577.1	7334.1	3682.6	7467.5	0
10	3294.3	6971.7	3391.5	7097.1	3491.5	7225.1	3594.4	7356.1	3700.4	7490.0	10
20	3310.3	6992.4	3407.9	7118.2	3508.4	7246.8	3611.9	7378.2	3718.4	7512.6	20
30	3326.4	7013.2	3424.5	7139.4	3525.5	7268.5	3629.4	7400.4	3736.5	7535.3	30
40	3342.5	7034.0	3441.1	7160.7	3542.6	7290.3	3647.1	7422.7	3754.6	7558.1	40
50	3358.8	7055.0	3457.8	7182.1	3559.8	7312.1	3664.8	7445.0	3772.9	7581.0	50
60	3375.1	7076.0	3474.6	7203.6	3577.1	7334.1	3682.6	7467.5	3791.2	7604.0	60

Minutes	106°		107°		108°		109°		110°		Minutes
	Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	
0	3791.2	7604.0	3903.1	7743.7	4018.5	7886.7	4137.4	8033.2	4260.0	8183.3	0
10	3809.6	7627.0	3922.1	7767.3	4038.0	7910.8	4157.5	8057.9	4280.8	8208.7	10
20	3828.1	7650.2	3941.2	7791.0	4057.7	7935.1	4177.8	8082.8	4301.7	8234.2	20
30	3846.7	7673.4	3960.4	7814.7	4077.5	7959.5	4198.2	8107.8	4322.7	8259.8	30
40	3865.4	7696.7	3979.6	7838.6	4097.3	7983.9	4218.7	8132.8	4343.8	8285.5	40
50	3884.2	7720.1	3999.0	7862.6	4117.3	8008.5	4239.3	8158.0	4365.1	8311.3	50
60	3903.1	7743.7	4018.5	7886.7	4137.4	8033.2	4260.0	8183.3	4386.4	8337.2	60

Minutes	111°		112°		113°		114°		115°		Minutes
	Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	
0	4386.4	8337.2	4516.9	8495.1	4651.6	8657.1	4790.7	8823.4	4934.4	8994.3	0
10	4407.9	8363.2	4539.1	8521.8	4674.5	8684.5	4814.4	8851.6	4958.9	9023.2	10
20	4429.5	8389.4	4561.3	8548.6	4697.5	8712.0	4838.1	8879.9	4983.4	9052.3	20
30	4451.2	8415.6	4583.7	8575.6	4720.6	8739.7	4862.0	8908.3	5008.1	9081.5	30
40	4473.0	8442.0	4606.2	8602.6	4743.9	8767.5	4885.0	8936.8	5032.9	9110.8	40
50	4494.9	8468.5	4628.9	8629.8	4767.2	8795.4	4910.2	8965.5	5057.9	9140.3	50
60	4516.9	8495.1	4651.6	8657.1	4790.7	8823.4	4934.4	8994.3	5083.0	9169.9	60

Minutes	116°		117°		118°		119°		120°		Minutes
	Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	Ext.	Tan.	
0	5083.0	9169.9	5236.6	9350.5	5395.4	9536.3	5559.7	9727.6	5730.0	9,924.6	0
10	5108.2	9199.7	5262.6	9381.1	5422.4	9567.8	5587.7	9760.0	5758.9	9,958.1	10
20	5133.6	9229.6	5288.9	9411.9	5449.5	9599.5	5615.8	9792.6	5788.0	9,990.6	20
30	5159.1	9259.6	5315.3	9442.8	5476.8	9631.3	5644.1	9825.4	5817.3	10,025.6	30
40	5184.8	9289.8	5341.8	9473.8	5504.3	9663.2	5672.6	9858.3	5846.8	10,059.7	40
50	5210.6	9320.1	5368.5	9505.0	5532.0	9695.3	5701.2	9891.4	5876.4	10,093.7	50
60	5236.6	9350.5	5395.4	9536.3	5559.7	9727.6	5730.0	9924.6	5906.1	10,127.7	60

$$L = 100 \times \frac{\Delta}{D} = \frac{\text{Central angle}}{\text{Degree of curvature}} \times 100.$$

For the convenience of the field engineer column 1, Table 32, gives the central angle (Δ) in degrees and minutes (as read by the transit); column 2 gives the same angle expressed in degrees and decimals for figuring curve lengths.

Tangent Length and Externals.—Sketch No. 71 shows a general curve problem. The deflection angle between the tangents at the point of intersection (P. I.) = the central angle of the curve that will fit these tangents; it is referred to as Δ.

The tangent distances equal the distance from the *P. C.* (beginning of curve) to the *P. I.* or *P. I.* to *P. T.* (end of curve) and is expressed by the formula

$$T = \text{Radius} \times \text{tangent of } \frac{\Delta}{2} \qquad (4)$$

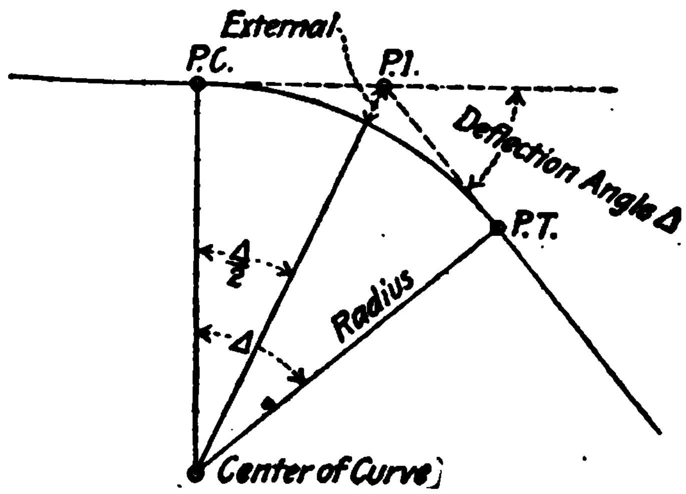


FIG. 71.

Therefore, for a given central angle Δ, the tangent length is directly proportional to the radius. If the tangent lengths of a 1° curve for different Δ's are tabulated, the tangent length for any desired degree of curve equals tangent length for 1° curve for the specified Δ divided by the degree of the desired curve expressed in degrees and decimals of a degree.

Expressed as a formula this reads:

$$\text{Tangent for desired curve} = \frac{\text{Tangent } 1^\circ \text{ curve for specified } \Delta}{D} \qquad (5)$$

and reversing the formula we can determine the desired degree of curve for a specified tangent length by the formula

$$D = \frac{\text{Tangent } 1^\circ \text{ curve for specified } \Delta}{\text{Specified tangent length desired}} \qquad (6)$$

The external is the distance from the *P. I.* to the curve arc on the line between the *P. I.* and the center of the curve. It is determined by the formula:

$$\text{Ext.} = \frac{\text{Radius}}{\text{Cosine}\frac{\Delta}{2}} - \text{Radius} = \text{Radius}\left(\frac{1}{\text{Cosine}\,\frac{\Delta}{2}} - 1\right) \qquad (7)$$

and is directly proportional to the radius in the same manner as the tangent length; therefore, the external of any desired curve for a specified Δ equals the external of a 1° curve for that Δ divided by the degree of curvature.

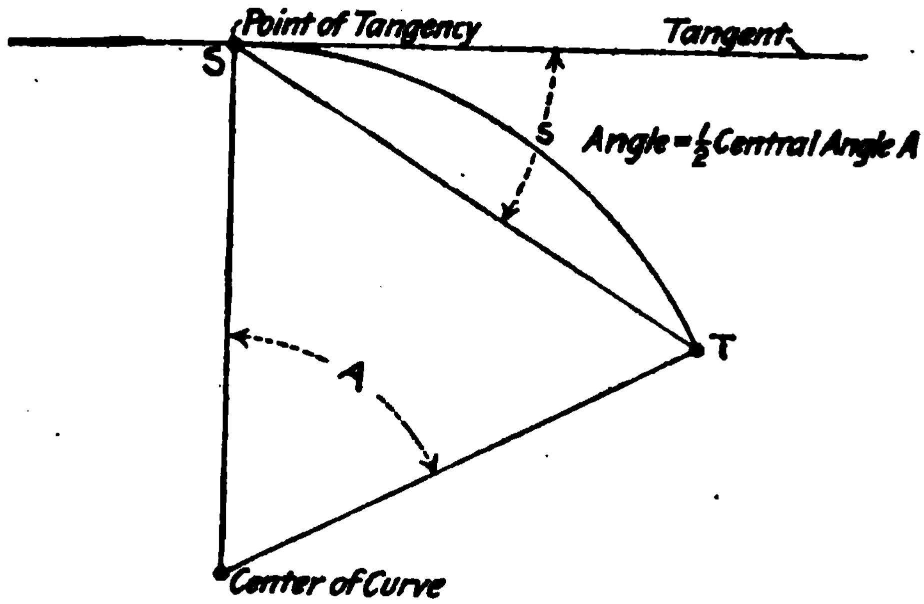


FIG. 72.

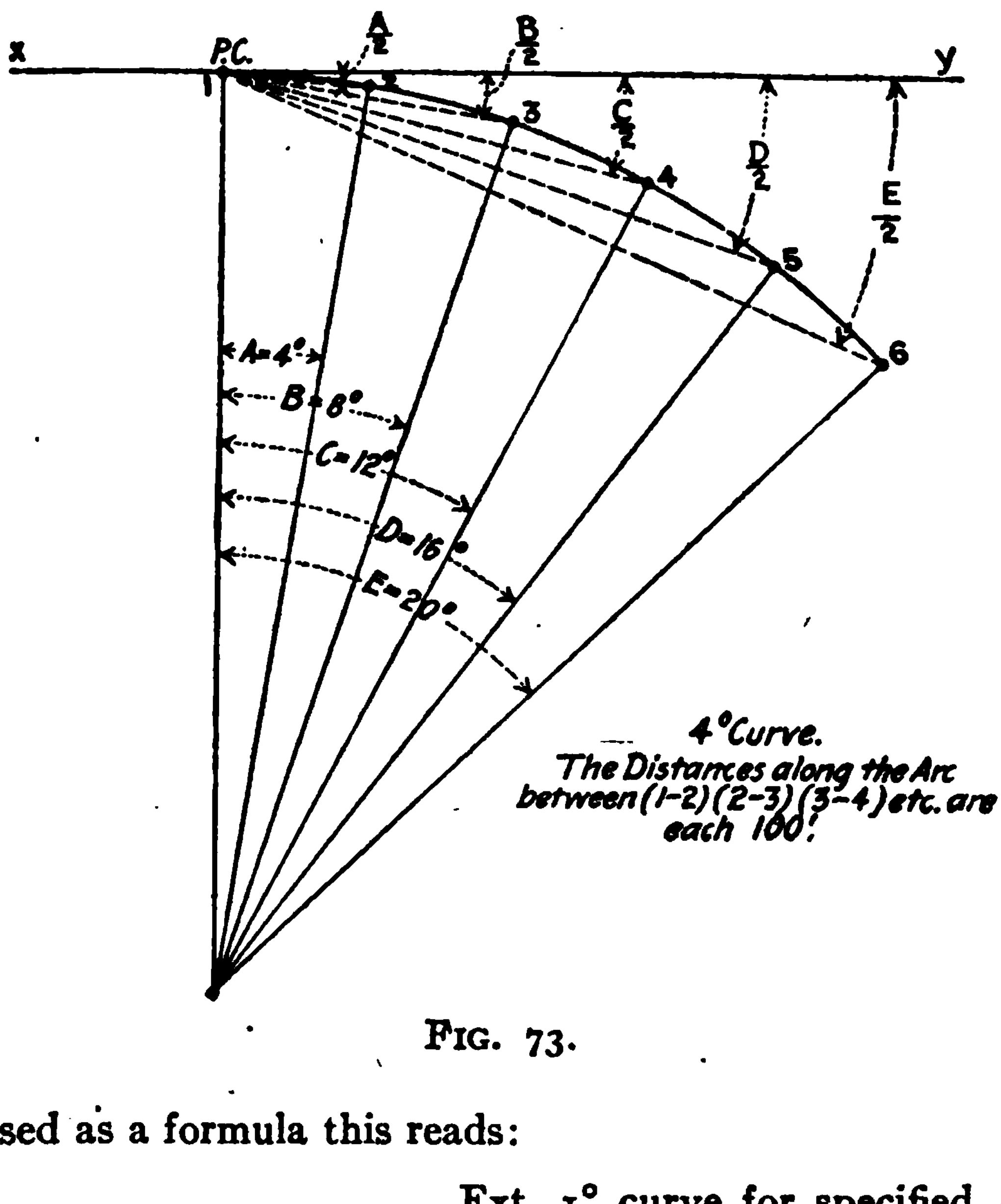


FIG. 73.

Expressed as a formula this reads:

$$\text{External for desired curve} = \frac{\text{Ext. 1° curve for specified } \Delta}{D} \qquad (8)$$

and reversing, as for tangents, the desired degree of curvature is obtained that gives a specified external distance, by the formula,

$$D = \frac{\text{Ext. } 1^\circ \text{ curve for specified } \Delta}{\text{Specified Ext. distance desired}}. \qquad (9)$$

Methods of Running Curves.—Curves are run in the field by tangent offsets, middle ordinates or deflection angles. Deflection angles is the simplest method and is almost universally used. It is based on the principle that the angle S between the tangent and arc chord, one end of which is at the point of tangency, is equal to ½ the central angle subtended by that chord. Suppose the angle A is 4° and the arc length $ST = 100$ feet. This curve would then be a 4° curve. From the previous definitions locate the point T (Fig. 72) by turning the deflection angle $S = 2^\circ$ from the tangent and measuring 100 feet of arc in such a position that the end of the arc would be on the line of the chord ST. It is impossible to conveniently measure the arc distance and for all practical purposes a chord length of 100′ will answer for a 4° curve (see discussion, page 379).

Suppose we wish to locate the points 2, 3, 4, 5, and 6 on the 4° curve from point 1 or the *P.C.* of a curve (Fig. 73).

Set the transit at the *P.C.*; if we turn a deflection $\frac{A}{2} = 2^\circ$ from the tangent xy the line of sight will pass through the point 2; if we turn $\frac{B}{2} = 4^\circ$ the line of sight will pass through point 3; 6°, point 4, etc.; it only remains to measure to these points to locate them definitely. This can be done in two ways, by measuring the distances 1–2, 1–3, 1–4, 1–5, etc., or by measuring 1–2, 2–3, 3–4, 4–5, etc.

In the first case the difference between the length of arc and the chord length becomes so great that, unless a correction is made, the points are not exactly located; that is, the length of arc between points 1, 2, 3, 4, 5, 6, = 500′ while the chord length 1–6 = 497.5′; also, it takes longer to measure the distances 1–2, 1–3, 1–4, 1–5, 1–6, etc., than it would 1–2, 2–3, 3–4, 4–5, etc.

In the second method we can use chords of 100′ from 1–2, 2–3, etc., with no appreciable error, as the distance measured by chords 1, 2, 3, 4, 5, 6, = 499.94′.

Therefore, the method usually adopted is to turn the deflection angle $\frac{A}{2}$ and measure the chord 1–2, which locates the point 2; then turn the deflection angle $\frac{B}{2}$ and measure the chord distance 2–3, locating point 3, etc.

The fact has been mentioned that the use of the chord distance as equal to the arc introduces an error but that this error is of no importance for a 4° curve: As the degree of curvature increases, the difference between an arc length of 100′ and the chord

length becomes greater, and it is necessary to determine the limit of curvature that will allow the use of 100′ chords in locating curve points. On page 324 the statement is made that center line chaining should be correct to within 0.1′ per 100′ of length, which allows a difference in arc and chord of 0.1. This occurs when the degree of curvature reaches 9° per 100′. The difference can then be reduced by the simple expedient of using 50′ chords, which reduces the error for this degree of curvature from 0.10′ per 100′ of length using 100′ chords to 0.02′ using 50′ chords; 50′ chords can be used up to 18° curves and beyond that point 25′ chords.

It is better not to use the full limit of allowable error, and a good working rule is 100′ chords up to 8° curves, 50′ chords up to 16° curves, 25′ chords to 32° and beyond that 10′ chords.

For any given curve the deflection angle and central angle are directly proportional to the length of the arc, and if the deflection angle for 100′ arc of 10° curve equals 5° the deflection angle for one foot of arc of 10° curve equals $\frac{5^\circ}{100} = \frac{300'}{100} = 3$ minutes.

An example of a typical simple curve problem can now be given:

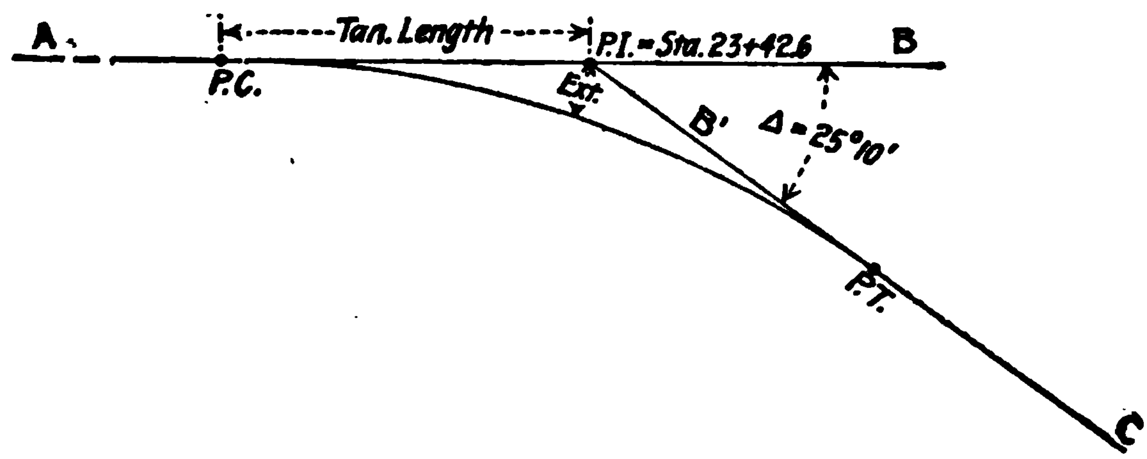


FIG. 74.

To determine the degree of curvature desired from a fixed external distance

At station 23 + 42.6 we have a deflection angle of 25° 10′ between tangents AB and $B'C$; suppose upon examining the ground it is decided that to fit the old roadbed and give good alignment the curve should be located somewhere between 13.5′ and 14.5′ to the right of the transit point at station 23 + 42.6. Proceed as follows: from table 32 pick out the external for a 1° curve for $\Delta = 25°\ 10'$, this equals 141.0′.

The problem is to determine the degree of curvature that will give an external of between 13.5′ and 14.5′. Use formula (9).

$$D = \frac{\text{Ext. } 1^\circ \text{ curve for } 25^\circ\ 10'}{13.5'} = \frac{141.0'}{13.5'} = 10.44^\circ \text{ curve.}$$

$$D = \frac{\text{Ext. } 1^\circ \text{ curve for } 25^\circ\ 10'}{14.5'} = \frac{141.0'}{14.5} = 9.72^\circ \text{ curve.}$$

To fit the conditions some curve must be selected between a 10.44° and a 9.72°. A 10° curve would be naturally selected as being the simplest to figure.

To determine the required degree of curvature for a fixed tangent length

Take the same problem as above except there must be a tangent length of between 127′ and 129′. Use formula (6).

$$D = \frac{\text{Tangent } 1^\circ \text{ curve for } 25^\circ\ 10'}{127'} = \frac{1279.1'}{127'} = 10.07^\circ \text{ curve.}$$

$$D = \frac{\text{Tangent } 1^\circ \text{ curve for } 25^\circ\ 10'}{129'} = \frac{1279.1'}{129'} = 9.91^\circ \text{ curve.}$$

Table 32 gives tangent for 25° 10′ = 1279.1′.

These limiting values would result in the selection of a 10° curve. The degree of the desired curve is usually selected in one of these two ways; ordinarily it is determined by the external distance.

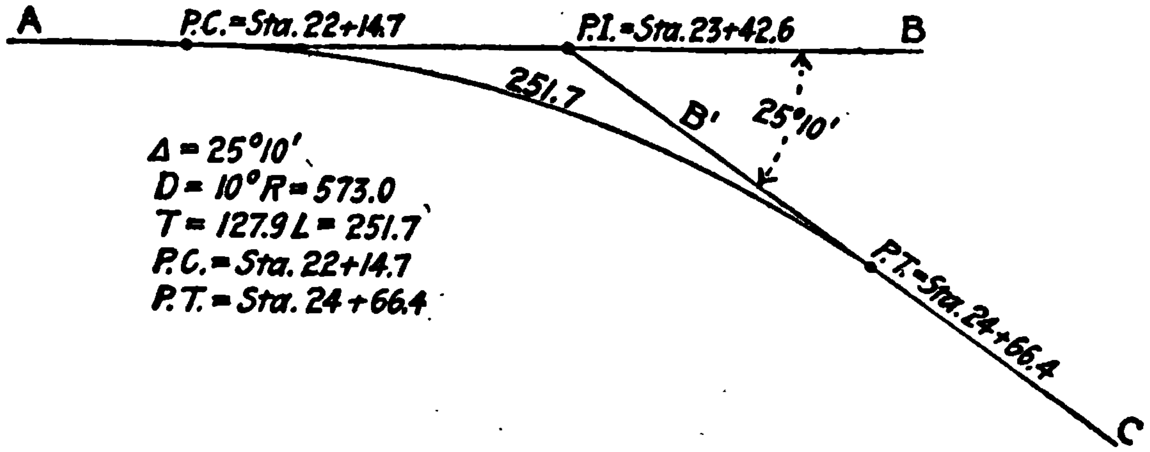


FIG. 75.

Simple Curve Problem. Case 1.—To compute the notes for a 10° curve for a deflection angle of 25° 10′ between tangents at station 23 + 42.6.

Central angle = 25° 10′.

Table 32 gives the tangent 1° curve for 25° 10′ = 1279.1.

Tangent 10° curve $= \dfrac{1279.1}{10} = 127.91.$

The station of the *P.C.* then equals station 23 + 42.6 *P.I.* minus 127.9′ = station 22 + 14.7.

The length of curve $= \dfrac{\Delta}{D} = \dfrac{25.16667^\circ}{10^\circ} \times 100' = 251.7$ feet.

The station of the *P.T.* (Tangent point, or end of the curve) as measured around the arc is then station (22 + 14.7 *P.C.*) + 251.7′ = station 24 + 66.4.

The rule for running curves requires the use of 50′ chords for

a 10° curve. We must, therefore, figure the deflections for the even stations and the 50′ stations as follows:

Station 22 + 50, 23 + 00, 23 + 50, 24 + 00, 24 + 50, and to check the curve station 24 + 66.4.

For a 10° curve, Table 31.

The deflection for 100′ of arc	=	5°
" " " 50′ " "	=	2° 30′
" " " 1′ " "	=	0° 03′

The distance from the *P.C.* station 22 + 14.7 to station 22 + 50 is 35.3′; the deflection per foot = 0° 03′, for 35.3′ = 35.3 × 0° 03′ = 105.9 minutes = 1° 46′.

The distance *P.C.* to station 23 + 00 equals 85.3′, or 50′ farther than for station 22 + 50; the deflection per 50′ of arc equals 2° 30′; therefore, the deflection for station 23 + 00 equals the deflections for station 22 + 50 (1° 46′) plus 2° 30′, the deflection for 50′ of arc or 4° 16′; in a like manner the deflection for station 23 + 50 is 6° 46′; for 24 + 00, 9° 16′; for 24 + 50, 11° 46′; the distance from station 24 + 50 to the *P.T.* station 24 + 66.4 is 16.4′; the deflection for 16.4′ equals 16.4 × 0° 03′ = 49.2′; the deflection for station 24 + 66.4 is, therefore (11° 46′ + 49′) = 12° 35′; if the deflection notes have been properly figured this last deflection to the *P.T.* should always be ½ the central angle of the curve; in this case ½ of 25° 10′, which equals 12° 35′, checking the notes.

To run the curve. Set up the transit at the *P.I.*; sight along the tangent (*B.A.*), measure off the distance 127.9′ (tangent length) along this line and set the *P.C.* exactly on the line. In a like manner set the *P.T.* on the forward tangent (*B′.C.*) 127.9′ from the *P.I.* Then set up the transit on the *P.C.* and with the vernier at 0° 00′ sight on the *P.I.*, using the lower plate motion. Loosen the upper motion and deflect 1° 46′; measure along this line 35.3′, which locates station 22 + 50 on the curve arc; then loosen the upper motion and set the vernier to read 4° 16′; measure 50′ from the just located station 22 + 50, so that the forward end of the tape is in line with the transit deflection of 4° 16′; this locates station 23 + 00 on the curve arc. In a like manner deflect 6° 46′ and measure forward 50′ from station 23 + 00 to station 23 + 50, etc., until the *P.T.* is reached. If the curve has been correctly run the last deflection of 12° 35′ will strike the previously located *P.T.* and the distance from station 24 + 50 to this *P.T.* will be 16.4′; if the distance checks within 0.2′ it is sufficiently close.

The above problem and method of laying out a curve is the simplest form encountered; in it we assume that the *P.I.*, *P.T.* and all intermediate points on the curve are visible from the *P.C.* and that the *P.I.* is accessible.

In nine cases out of ten this method is applicable to road curves, but where the *P.I.* occurs outside of the road fences it sometimes is located in a stream, pond, building, etc., and cannot be occupied. This is known as the problem of the inaccessible *P.I.* More often it is impossible to see the *P.T.*, or some intermediate point on the curve from the *P.C.*, which necessitates intermediate

transit points on the curve. The problem of inaccessible *P.C.s* or *P.T.s* is so rare it will not be illustrated.

Problem of the Inaccessible P. I. Case 2.—The point *H* (*P.I.*) can not be occupied. Locate any two convenient points, *s* and *t* on the tangents *A.B.* and *B'.C.* and measure the distance *st* equals, say, 110.5'.

Set the transit at *s* and measure the angle between the line *A.s.* produced and *st*, say, 5° 10'; in a similar manner measure the angle at *t* between *st* produced and the forward tangent *tC*, say, 20° 00'. The total deflection then between the tangent *AsB* and *B'tC* or the central angle of the curve to be run is the sum of these two deflections, angles (5° 10') + (20° 00') = 25° 10'.

Assuming a 10° curve is desired we must locate the *P.C.* from the point *s* and the *P.T.* from the point *t*.

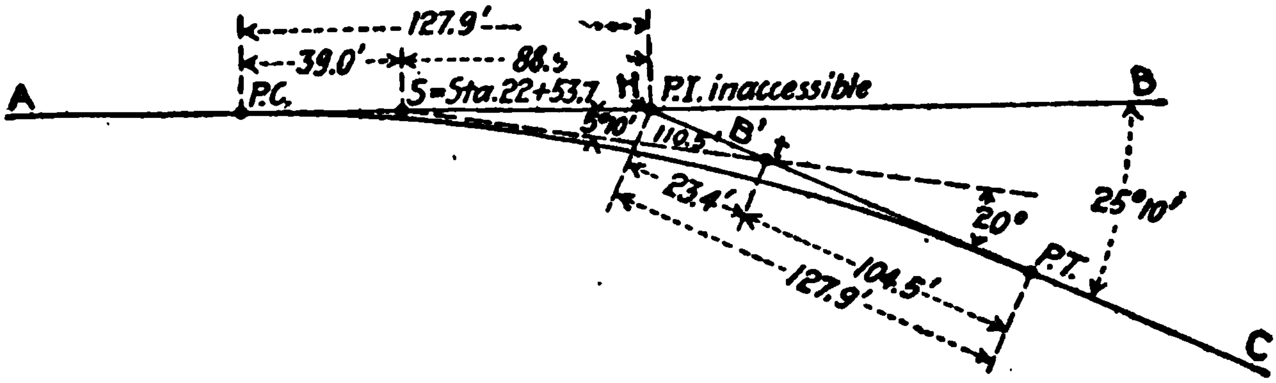


FIG. 76.

In the preceding simple curve problem the tangent length of a 10° curve with a central angle of 25° 10' was figured to be 127.9'; it, therefore, remains to compute the distance *sH* which subtracted from 127.9' will give the distance from *s* along the tangent *sA* to the *P.C.*, of the curve. In a similar manner compute *tH*, which subtracted from 127.9' gives the distance along the forward tangent *tC* to the *P.T.* of the curve.

Knowing the station of the point *s* as measured along the tangent *A.B.* the station of the *P.C.* is determined; then figure the deflections in the usual manner and run the curve.

For the values given the computations are as follows:

To determine *sH* and *Ht*. Use the law of sines (see Trigonometric formulæ, page 843).

$sH : st : \sin 20°\ 00' : \sin 25°\ 10'$

$$sH = \frac{st \sin 20°\ 00'}{\sin 25°\ 10'} = \frac{110.5 \times 0.34202}{0.42525} = 88.87'$$

$$Ht = \frac{st \sin 5°\ 10'}{\sin 25°\ 10'} = \frac{110.5 \times 0.09005}{0.42525} = 23.4'$$

Therefore, the distance from *s* to the *P.C.* is 127.9' − 88.9' = 39.0'.

The distance from *t* to the *P.T.* is 127.9 − 23.4 = 104.5.

Having these distances the *P.C.* and *P.T.* are located. As-

sume that station of s was measured along the tangent AB and found to be station 22 + 53.7.

The station of the *P.C.* then equals 22 + 14.7
" " " " *P.I.* " " 23 + 42.6
" " " " *P.T.* " " 24 + 66.4, using the length of curve figured in *Case* 1.

The deflections are figured and the curve run as in Case 1, assuming that all the curve points are visible from the *P.C.*

Case 3.—*Where the P.T. or intermediate points on the curve are not visible from the P.C.*

(*a*) *Where an intermediate set-up is required. Use the same curve as in Case* 1.

The deflections for the different curve points were figured as follows:

Deflections.—*Instrument at P.C., foresight on P.I.*

P.C. Station	22 + 14.7	Deflection	0° 00′
	22 + 50	"	1° 46
	23 + 00	"	4° 16′
	23 + 50	"	6° 46′
	24 + 00	"	9° 16′
	24 + 50	"	11° 46′
	24 + 66.4	"	12° 35′.

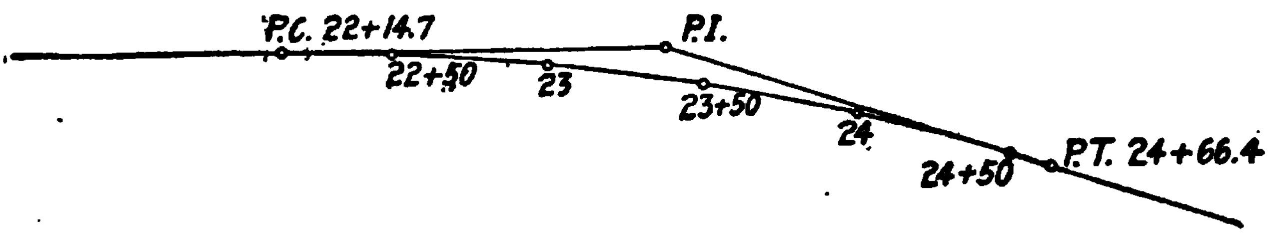


FIG. 77.

Set up the instrument at the *P.C.* and locate the points 22 + 50, 23 + 00 and 23 + 50; suppose 24 + 00 is not visible, set up at station 23 + 50, set the vernier at 0° 00′ and back sight on the *P.C.*; transit the telescope and finish the curve, using the same deflections as figured for the instrument set up at the *P.C.*; that is, turn the deflection of 9° 16′ for station 24 + 00, 11° 46′ for 24 + 50, and 12° 35′ for the *P.T.* In general it can be said that whenever the *P.C.* is used as a backsight from the intermediate set-up, set the vernier at 0° 00′ when sighting on the *P.C.*; transit the telescope and use original notes for the balance of the curve.

(*b*) *Where two or more intermediate set-ups are required.*

For the first set-up, say, at 23 + 50, proceed as above and set station 24 + 00; suppose 24 + 50 is not visible from station 23 + 50; set up at station 24 + 00 and with the vernier reading 6° 46′ back sight on station 23 + 50; transit the telescope, set the vernier to read 11° 46′ for station 24 + 50, and proceed, using the same deflections as originally figured. In general, where the *P.C.* is not visible from the intermediate set-up, set the vernier to read the deflection figured for the point used as a backsight; transit the telescope and proceed with the curve,

using the notes originally figured. That is, if the instrument is set up at station 24 + 00 and 22 + 50 used as a backsight, the vernier is set at 1° 46′, and using the lower motion the wire is set on station 22 + 50; then transiting the telescope the curve is run by setting the vernier at 11° 46′ for station 24 + 50, etc.

If station 23 + 00 is used as a backsight, set the vernier at 4° 16′ when sighting the machine; then transit and proceed as above.

These three cases cover any ordinary road curve problems.

(*b*) NEW LOCATION SURVEYS

General.—The details of survey work depend entirely on the character of the improvement and range from simple alignment determination on Mesa Wagon trails to the complete surveys required for difficult mountain locations which are to be constructed by contract on unit price bids. The following data are for complete first-class surveys. The same methods are used for more incomplete surveys but parts of the procedure can often be omitted if the work is to be done by force account or convict labor.

Organization and Equipment.—Eight to ten men parties are a convenient and efficient force.

Locating engineer
Transitman
Levelman
3 Chainmen, rodmen, etc.
1 to 3 Axemen.
Cook

If drafting is to be done in the field add a draftsman and computer to the party, but this is not advised as field drafting is rarely satisfactory.

Organization. (First stage of work.)

Locating engineer	Picking out line and general supervision.
Transitman 2 Chainmen Necessary axemen 1 Stakeman	Running base line.
Levelman Rodman	Running bench levels and check profile levels. Keeps all this work close up to base line party.

Organization. (Second stage of work.)

Locating Engineer 1 Assistant	Drainage areas. Classification of materials and topography.
Transitman 2 Assistants	Cross-sections.
Levelman 2 Assistants	Cross-sections.

Extra men moving camp, odd jobs, etc.

The first stage of the work varies in speed from ½ mile to 3 miles per day depending on the character of the county. Three-fourths mile per day is a fair average for ordinary mountain work.

The second stage should make a speed of from 1 mile to 2 miles per day. A fair average is about 1½ miles per day.

Allowing for unavoidable loss of time, moving camp, etc., 10 miles a month for an eight man party is a fair average when they are doing first class work.

Cost of Survey.—The cost of first class complete mountain road location surveys runs from $75 to $150 per mile exclusive of railroad transportation to the job, allowing $150 per month for the locating engineer, $120 per month for transitman; $100 per month for leveler and $70 to $90 for laborers, etc. Meals are furnished free to the men at an average cost of $0.75 per man per day exclusive of labor or about $1.00 to $1.30 per day including cooks salary.

The average speed for a party of 8 men is approximately 10 miles per month of completed survey, at an average cost of $100 to $120 per mile exclusive of railroad transportation. In easy flat country this speed can be easily doubled and the cost halved.

DEPRECIATION ON ENGINEERING EQUIPMENT PER MILE OF SURVEY

Assumed 50 miles of survey per season

Quantity	Item	Value	Approx. Life, Years	Annual Depreciation and Repairs	Rental Charge per Mile Survey
1	Transit (mountain) tripod	$300.00	10	$40.00	
1	Level (dumpy or Y)	150.00	10	25.00	
1	Locke level	7.00	3	2.50	
2	Abney levels @ $16.50	33.00	5	6.00	
3	100′ chains @ $12.00	36.00	2	18.00	
4	Range poles (8′ wooden) @ $2.25	9.00	2	5.00	
2	Level rods, Philadelphia 13′ extension	30.00	1	30.00	
2	Chain repair kits	20.00	5	4.00	
3	Metallic tape boxes, $2.45	7.00	1	7.00	
6	Metallic fillers	6.00	1	6.00	
1	Set sounding bars (1¼″–1″ and ¾″ tool steel)	10.00	10	1.00	
4	Plumb bobs	4.00	2	2.00	
2	Pocket compasses	4.00	3	1.50	
1	Kodak 3-A	24.00	4	6.00	
1	Engineer's trunk	10.00	1	10.00	
	Totals	$650.00		$164.00	$3.30 (Say $3.00)

* Marking crayon.

* Use a crayon having a large amount of oil as it will last longer. "Stay-On-All" is a good brand.

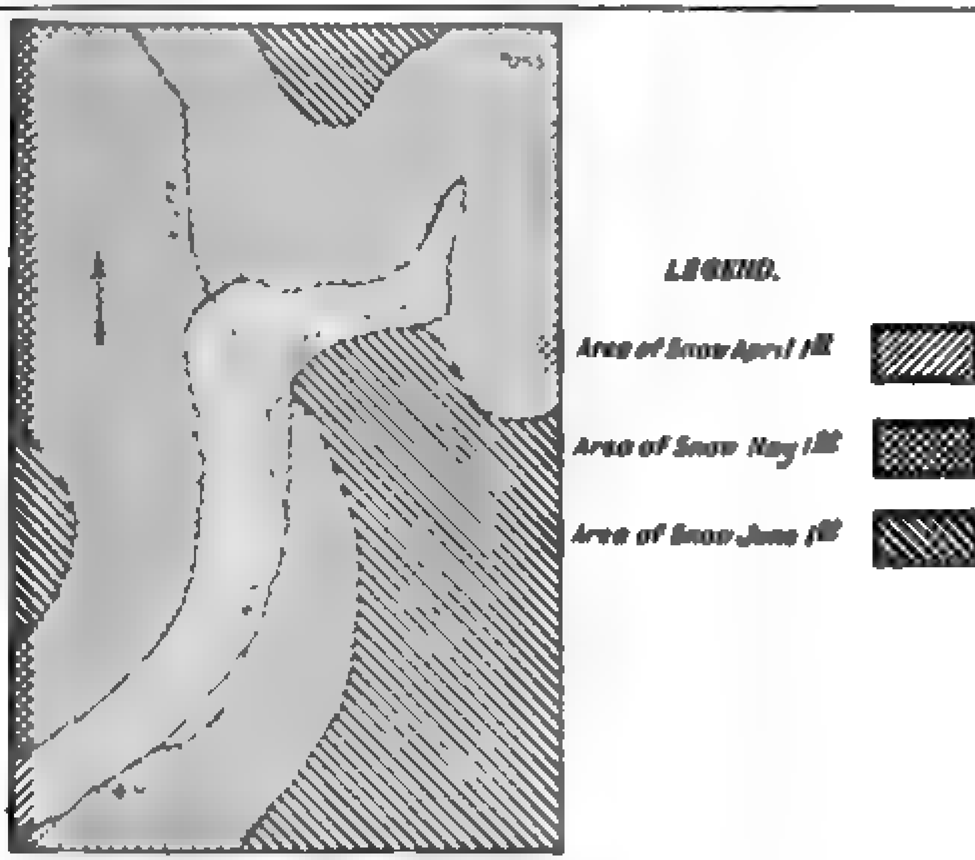
Camp Drafting Equipment (if desired).—Camp equipment is listed in Chapter XII.

Methods.—The chief of party should precede the men to the work and go over the entire line as outlined in the preliminary investigation report picking out his camp sites and making all necessary arrangements for transportation of camp equipment and supplies. He should also mark the base line location for two or three miles so that when the party arrives there will be no delay in making camp and starting the line work.

First Stage of Survey.—

(*a*) Tracing the location.
(*b*) Running base line.
(*c*) Running bench levels and base line profile.

(*a*) **Locating Line.**—This work is done by the locating engineer who considers all the principles of grade, alignment, etc., discussed in Part I. In high altitudes he pays particular attention to avoiding bad snow conditions which in general means avoiding north exposure as much as possible. Very often he can be helped in this part of the problem by making a snow map the spring preceding



NOTE.—This map shows that it is advisable to keep on the north side of Buck Creek and the west side of Wind River from the standpoint of avoiding snow. It also shows that the Pass was open by June 1st.

FIG. 79.

the survey. This is done by sketching in the areas where snow lies at different dates, say April 1st, May 1st, June 1st. When furnished with a map of this kind he avoids the areas of late snow where possible. Lacking a definite investigation for snow conditions the best available local data should be obtained from hunters, etc.

The different trial lines are traced with an Abney level in open country and a combination of Abney level and aneroid in timbered country. The line that he decides to adopt is marked at sufficiently close intervals either by blazing trees or tall stakes with flags on them so that the base line party will have no difficulty in following the correct location. This work must be kept far enough ahead of the base line party so that there is no danger of the work of the main party becoming worthless by the line getting into a location which has to be abandoned and relocated.

When working on a ruling grade the line should be traced down hill from the highest point on the route. When working on a ruling grade the line in the field should always be traced at a less rate of grade than the maximum allowed. That is if the maximum grade is set at 7% the locator should trace his line on a 6½ or 6% grade in order to give the designer a little leeway for economical variations from the field grade and yet keep within the maximum rate. When working on portions of the route requiring less than the ruling grade it makes no difference in which direction the line is traced so long as the base line is run in one direction with continuous stationing.

(*b*) **Base Line.**—The base line follows the marked route of the location. It is a chained, transit line marked on the ground by stakes at least every 100 feet well driven and marked with crayon (Stay on All) with the station or plus of each stake. Stakes are placed at each point on the line where a profile shot or cross-section will be required and should be well made and well driven so that they will remain in place at least three years. The transit points (angle points) are marked with well driven hubs with tack centering; every third or fourth transit point should be permanently and carefully referenced by both azimuth and distance (see sample notes). The angles in the line are determined by transit readings and the bearings of the courses are recorded by azimuth using true north as the zero azimuth. The use of true north as the reference line in these surveys is desirable on account of permitting a check on the accuracy of the transit work at any time; on account of retracing a lost line and on account of right-of-way descriptions in localities laid out on the U. S. Land system. The methods of determining true meridian by polaris and solar observations are explained, pages 395 to 415. In fairly flat or rolling topography the base line should follow the center line of the proposed improvement exactly and all curves at tangent intersections should be run in the field. It has been found from experience that for the topographic conditions mentioned that the field men can pick the best location in easy country and also that where the center line is actually run and staked that it simplifies the work of cross-sectioning, the office design and the staking for construction.

However, on sidehill locations or any kind of difficult work experience has shown that the field men can not pick an exact center line which will be economical in design and that under these conditions it is a waste of time and money to run in curves. Under these conditions the base line is run as a series of tangents keeping as close to the probable center line as possible and using short tangents in going around any natural features that will require a sharp curve in the finished road. Later when the cross-sections are taken they must be extended far enough from the line to allow the designer to shift the center line from the base line as

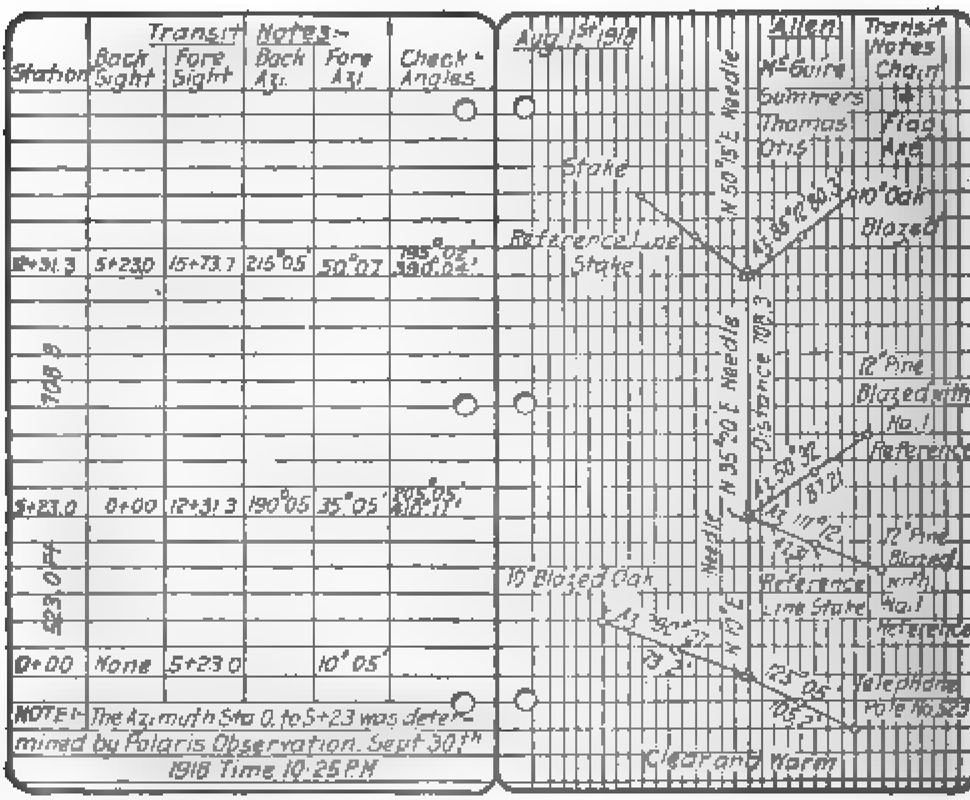


FIG. 80.

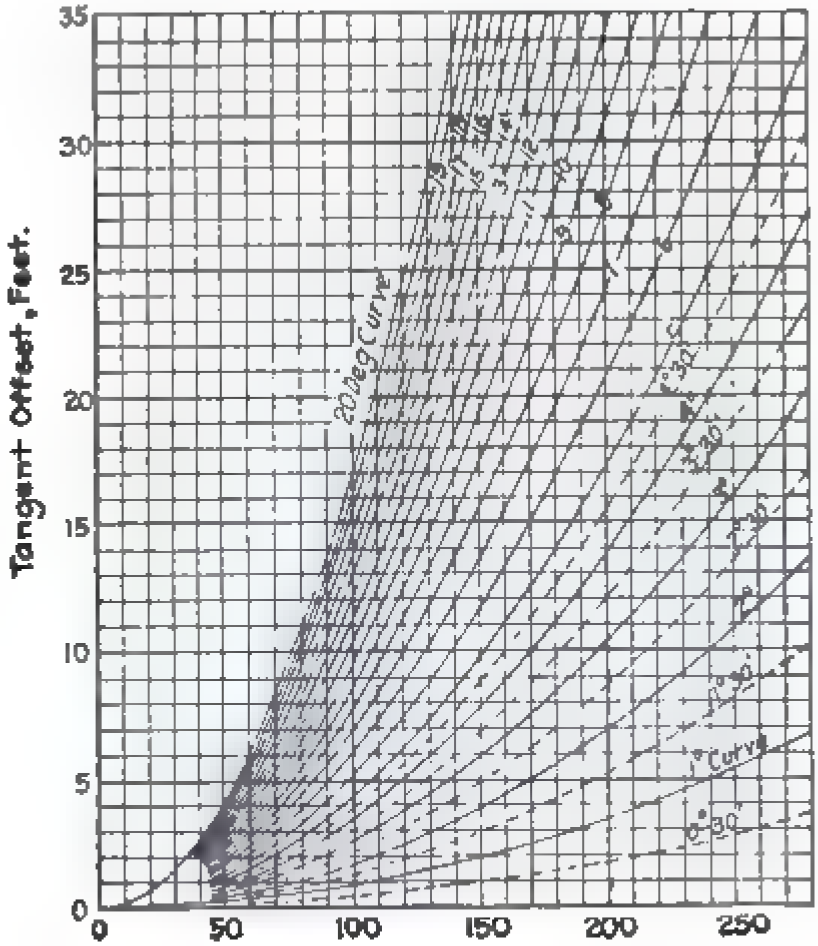
far as he desires as well as varying his vertical grade from the field grade. This requires considerable extra work in cross-sectioning as will be taken up later but is well worth while, as in difficult country a paper location is always more economical to construct than a field location.

Bench Levels.—Ordinary engineers spirit level work reading turning points to nearest 0.01 of a foot. Benches figured to nearest 0.01 ft. in elevation (see sample notes. Figure 81).

Permanent benches should be established at least every ½ mile and preferably at ¼ mile intervals. The datum for the levels should be referred to U. S. Geological Survey datum if possible or lacking this reference a datum can be assumed but in any case the method of arriving at the elevation of the initial bench mark

(*Continued page* 390)

STAKING CURVES BY TANGENT OFFSET



Distance in feet measured along the curve from the P.C. or P.T.

FIG. 81.

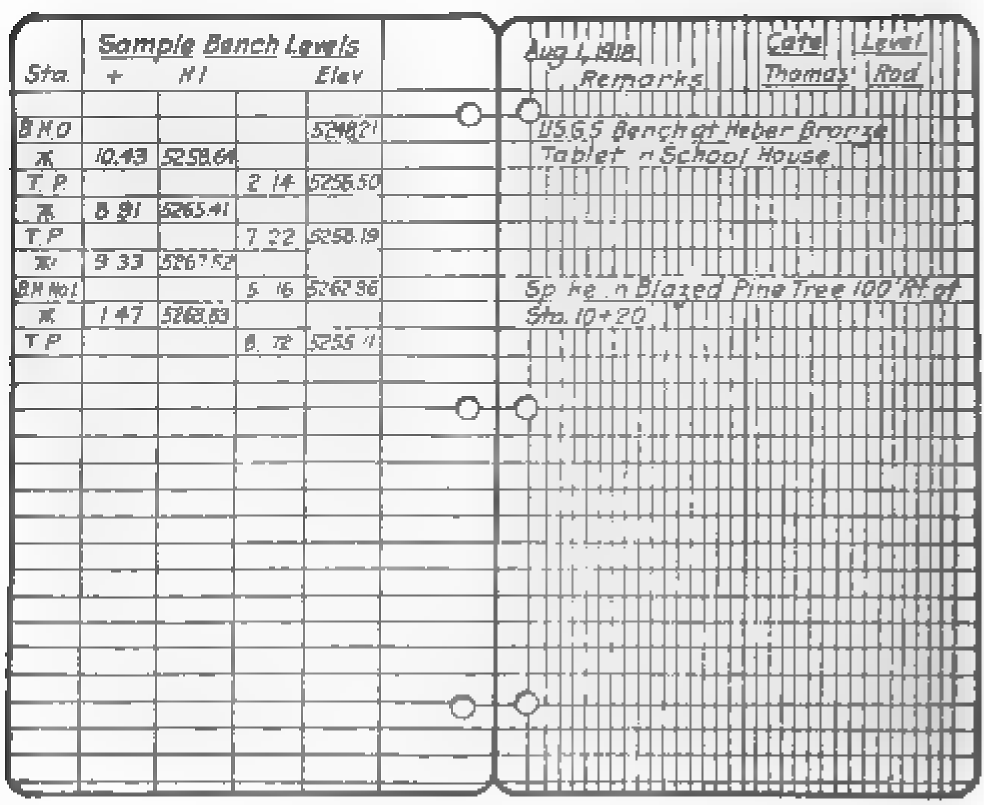
The following instructions accompany the chart:

In measuring up to the P. I., leave temporary markers at enough points so that the line of the tangent can be readily located by eye. From the newly located P. I. turn off the desired deflection angle. Determine the degree of curve necessary to fit the conditions from the external and tangent length and take from table the tangent and length of curve, and record the station of the P.C. and P.T. Make the curve correction for difference in length of the sum of the tangents and distance on the curve at the P.I., and start measurements along next tangent, leaving temporary markers up to the P.T. of the curve. To lay out curve, start at the station or plus station near the P.C. and measure along the curve, using standard chord lengths, and using the offsets from tangent as read from chart, which increases as the distance from the P.C. or P.T. increases.

To be useful a chart of this kind should be drawn to a larger scale than we can reproduce in a handbook of this size and this has been inserted more to show a convenient method than for actual use. In the same manner a chart can be prepared for short radii curves from 40′ radius to 150′ radius that is very useful in mountain road location.

should be fully explained in the notes. The computations of level notes should be made in the field and checked each night.

Profile Levels.—These levels also act as a check on the bench levels and therefore require an independent line preferably run in the opposite direction. The turns are read to the nearest 0.01 foot and the profile ground elevations of the base line to the nearest 0.1 foot. In case there is no radical difference in the two lines of levels (Bench and Profile) the profile levels are corrected to agree with the bench levels at each bench and carried ahead on the bench elevations. This is done so that there will be no cumulative difference in the levels. An error of 0.1 foot in running between benches



is allowable (see Figure 82 for sample profile level notes). Level computations should be figured and checked each night and a pencil profile plotted for the convenience of the locator.

Second Stage of Work

(*a*) Cross-sections.
(*b*) Topography.
(*c*) Drainage.
(*d*) Classification of materials.
(*e*) Field drafting.

(*a*) **Cross-sections.**—Cross-sections are the most important part of the detail work on survey. The tendency is to slight this part of the work as it is tedious and uninteresting. The author has seen so much trouble experienced in the office design due to inadequate cross-section field work that he wishes to emphasize the

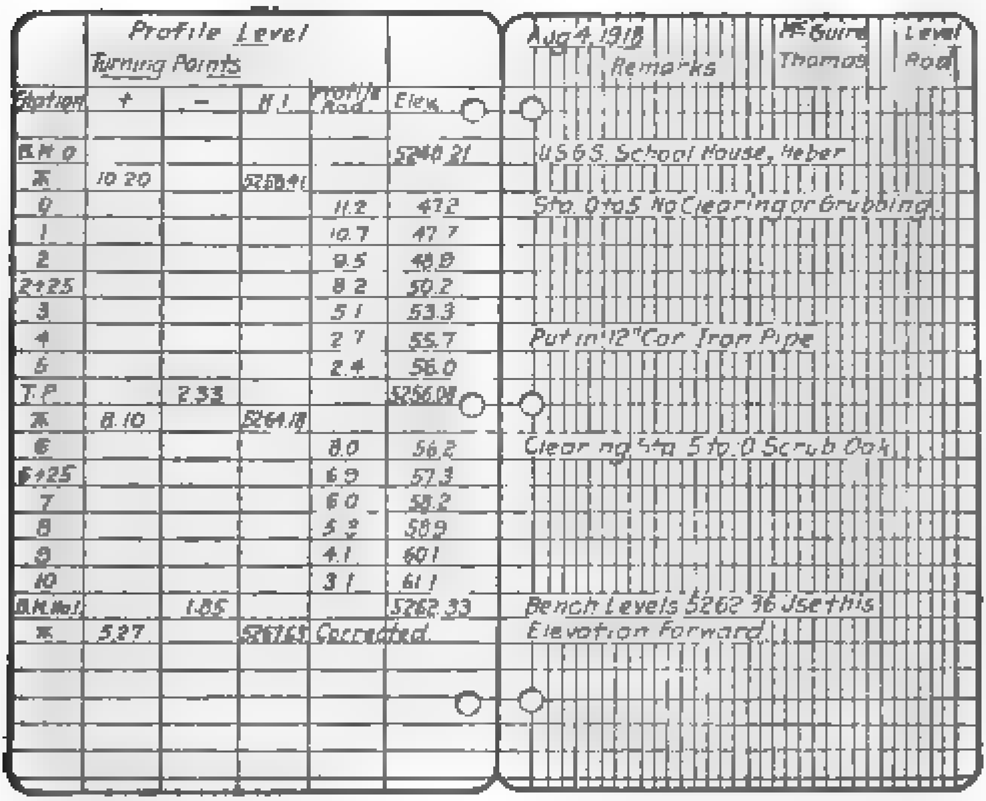
importance of taking wide enough sections particularly where a paper location is contemplated.

In level country where center line is exactly run 30 feet each side of the center line is enough.

In hilly country on side slopes averaging 25° where the center line is exactly located 60 feet each side of the line is enough.

Where the center line is not exactly located the engineer must use his judgment but as a rule it is not safe to use less than 100 feet each side of the line.

For switchback turns or where a large variation from the survey base line is probable a careful stadia survey is desirable.



Station	Profile Level Turning Points +	−	H.I.	Profile Rod	Elev.	Aug 4 1919 Remarks	McGuire Thomas	Level Rod
B.M. 0					5240.21	U.S.G.S. School House, Heber		
⊼	10.20		5250.41					
0				11.2	47.2	Sta. 0 to 5 No Clearing or Grubbing		
1				10.7	47.7			
2				9.5	48.9			
2+25				8.2	50.2			
3				5.1	53.3			
4				2.7	55.7	Put in 1/2" Cor Iron Pipe		
5				2.4	56.0			
T.P.		2.33			5256.08			
⊼	8.10		5264.18					
6				8.0	56.2	Clearing Sta 5 to 0 Scrub Oak		
6+25				6.9	57.3			
7				6.0	58.2			
8				5.3	58.9			
9				4.1	60.1			
10				3.1	61.1			
B.M. No 1		1.85			5262.33	Bench Levels 5262.36 Use this		
⊼	5.27		5267.65	Corrected		Elevation Forward		

FIG. 82.

In flat country cross-sections are taken with the engineers level, rod and metallic tape in a similar way to the methods described in the first of this chapter for high class improvements.

In rough country they are generally taken with a hand level, rod and tape and each section is referred to the profile ground elevation of the base line (see sample notes, Figure 83). The absolute elevation of each point is figured from the base line ground elevation. This is important as while it entails more field computation they can be done at night, and by the use of the absolute elevations the office and design work is made simpler, cheaper and more accurate. Experience has demonstrated that the method of absolute elevations for cross-sections is much superior and cheaper in the end than relative elevations.

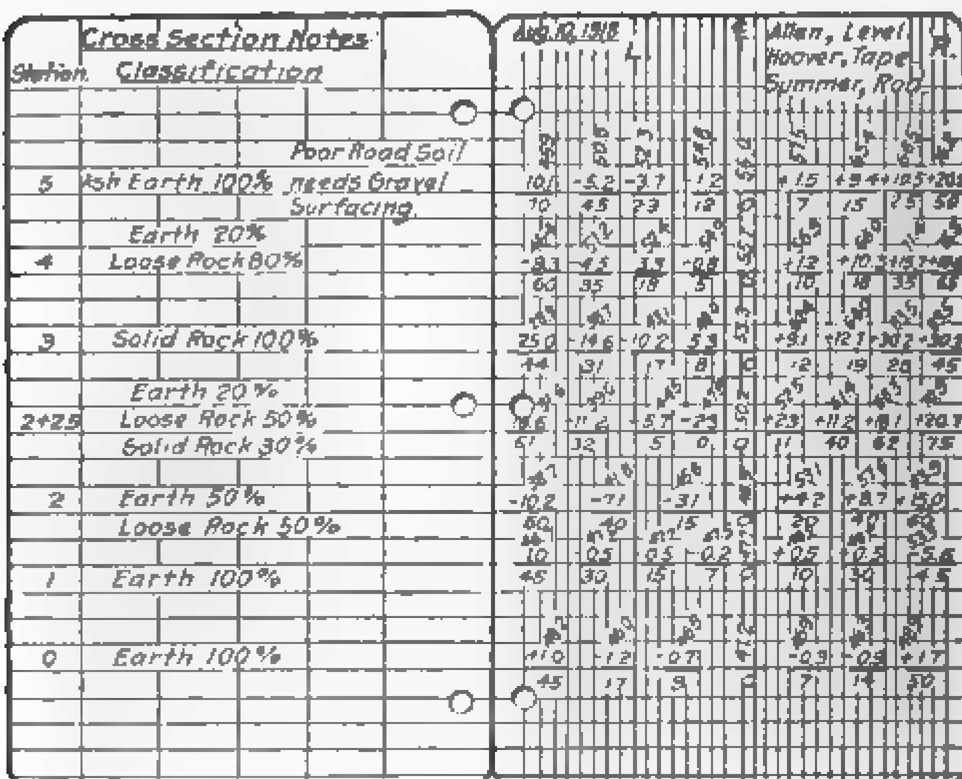
Cross-sections are taken at all breaks in the profile and in uniform topography at least every 100 feet and preferably at shorter intervals.

Special cross-sections are taken for all drainage crossings and show the skew angle of the proposed structure (see Figure 83).

Cross-section notes should be computed and checked each night.

(*b*) **Topography.**—Taken in the same manner as previously described (see sample notes, Figure 84).

(*c*) **Drainage.**—Field drainage notes on new locations must be detailed and specific as the recommendations determine the office design absolutely; there is no possibility of the designer checking the conclusions.



Such notes should be made personally by the chief of party and should indicate exactly where he wants the culverts or bridges placed and the size of opening of the structure. He uses the principles discussed in the chapter on drainage, and determines the size of waterway either from the physical evidence of high water or from the area of the drainage basin. Areas can be run out by paced, hand compass traverses, determining the divide lines with a hand level or can be plotted directly in the field on a small 9″ or 15″ plane table.

The type of structure as log, corrugated pipe, concrete box, etc., should be stipulated for each structure, as the field man is the only one who can decide on the best type, considering the local materials that are available.

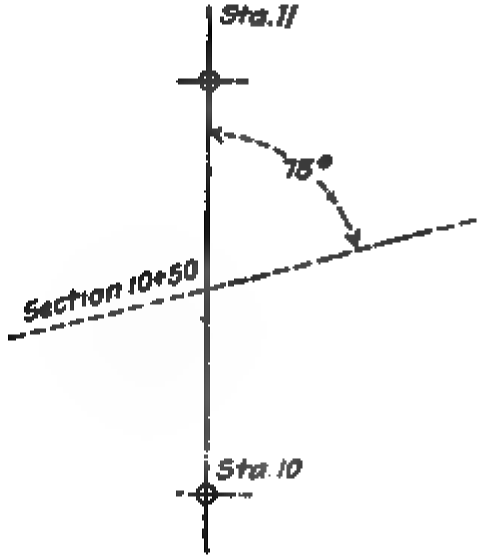

Sta. 11
75°
Section 10+50
Sta. 10

Fig. 83.

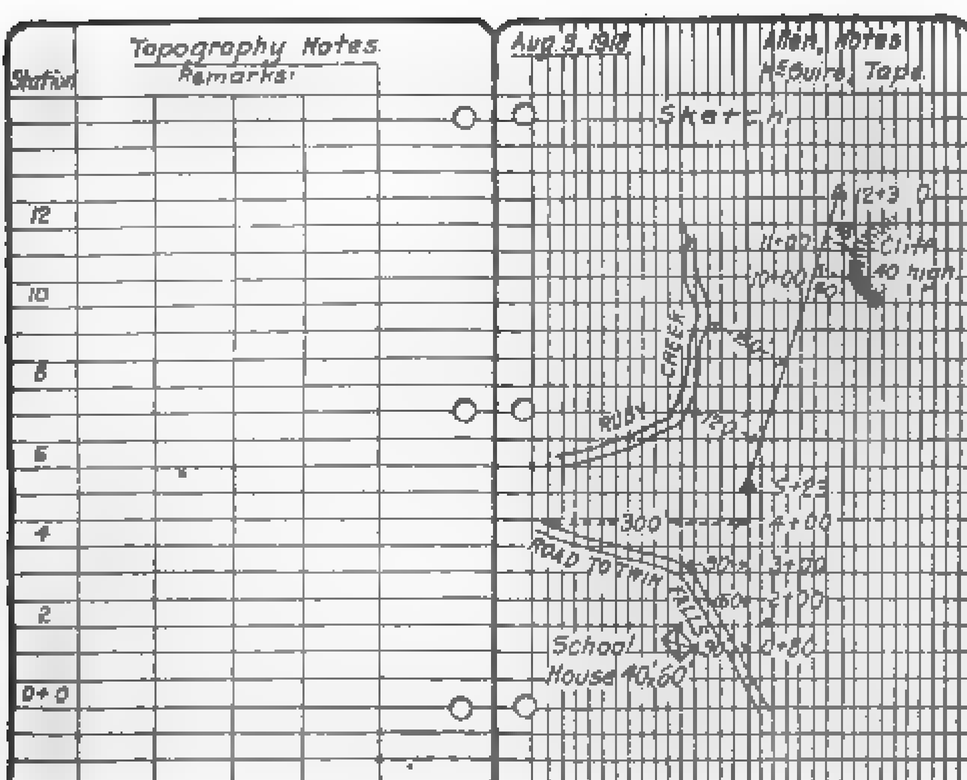

Topography Notes
Station
Remarks
12
10
8
6
4
2
0+0
Aug. 9, 1918
Allen, Notes
McGuire, Tape
Sketch
Cliff
40 high
11+00
10+00
Ruby
Creek
5+23
300
4+00
Road to Twin Falls
3+00
1+00
0+80
School
House 40, 60

Fig. 84.

(*d*) **Classification of Material.**—The classification of material has a marked effect on office design and should be handled by the chief. The expenditure of considerable time and money is justified in determining the sub-surface conditions within the probable limits of proposed excavation where there is reason to believe that solid rock will be encountered. This is done by bar soundings and test pits. Where the soil contains a large percentage of boulders bar soundings are of little value. As a rule it is impracticable to determine more than a general classification for the largest part of the distance unless rock outcrops show on the surface.

(*e*) **Field Drafting.**—The field drafting should be confined to special problems desired by the chief and should only be done where there is doubt as to whether sufficient field data has been obtained for the office design.

Complete design in the field is costly and is rarely as satisfactory as office design. Camp is no place for careful design.

Location Survey Reports.—A report should be worked up as the survey progresses. The object of this part of the record is to make it possible for a man not personally familiar with the ground to make a reasonable design. It should include all information of a general or special nature not shown in the survey notes such as:

1. A description of the general topography.
2. A description of alternate locations and the reasons in detail for the selection of the route surveyed.
3. A statement of the portions of the line where the survey alignment should be rigidly adhered to and an undulating grade used.
4. A statement of the portions of the line where the alignment can be shifted to fit a grade contour and a ruling grade adhered to.
5. The portions of the line where both line and grade can be varied in the final design.
6. Snow conditions and how bad exposure is avoided or why it can not be avoided.
7. Special designs to fit unusual conditions.
8. Special designs utilizing supplies of nearby local materials.
9. Photographs to illustrate special features or to give a general idea of conditions.

Determination of True North.—The simplest method of determining the true meridian is by observation on Polaris at elongation. For all practical purposes fairly close results can be obtained by observation on Polaris or the Sun at any time. The following tables and explanation of simple methods are quoted or briefed from the Manual of the United States Geodetic Survey on Magnetism and the determination of the true meridian, and the Metro Manual of the Bausch & Lomb Optical Co.

Meridian by Polaris at Elongation.—For all practical road survey purposes a determination of the meridian to the nearest minute of angle is sufficiently close. For one-half hour before elongation to a half hour after elongation the azimuth of Polaris does not vary over 30 seconds of angle which gives plenty of time for check determinations and the element of exact standard time is of little importance.

The following instructions for determining meridian at elongation by transit observation and by plumb line and peep sight are quoted from the U. S. Geodetic Manual.

SIMPLE METHODS FOR DETERMINING THE TRUE MERIDIAN BY OBSERVATIONS ON POLARIS[1]

(U. S. Geodetic Manual)

I. To Determine the True Meridian by Observation on Polaris at Elongation with a Surveyor's Transit

(Be sure transit is in good adjustment)

"1. Set a stone, or drive a wooden plug, firmly in the ground and upon the top thereof make a small distinct mark.

"2. About thirty minutes before the time of the eastern or western elongation of Polaris, as given by the tables of elongation, No. 33, set up the transit firmly, with its vertical axis exactly over the mark, and carefully level the instrument.

"3. Illuminate the cross hairs by the light from a bull's-eye lantern or other source, the rays being directed into the object end of the telescope by an assistant. Great care should be taken to see that the line of collimation describes a truly vertical plane.

"4. Place the vertical hair upon the star, which, if it has not reached its elongation, will move to the right for eastern and to the left for western elongation.

"5. As the star moves toward elongation, keep it continually covered by the vertical hair by means of the tangent screw of the vernier plate, until a point is reached where it will appear to remain on the hair for some time and then leave it in a direction contrary to its former motion, thus indicating the point of elongation.

"6. At the instant the star appears to thread the vertical hair, depress the telescope to a horizontal position; about 100 yards north of the place of observation drive a wooden plug, upon which by a strongly illuminated pencil or other slender object, exactly coincident with the vertical hair, mark a point in the line of sight thus determined; then *quickly* revolve the vernier plate 180°, again place the vertical hair upon the star, and, as before, mark a point in the new direction; then the middle point between the two marks, with the point under the instrument, will define on the ground the trace of the vertical plane through Polaris at its eastern or western elongation, as the case may be.

"7. By daylight lay off to the east or west, as the case may require, the proper azimuth taken from the Table 34; the instrument will then define the *true meridian*, which may be permanently marked by monuments for future reference."

[1] In the preparation of this article use has been made of the United States Land Office Manual of Instructions, Washington, 1896.

TABLE 33.—LOCAL MEAN (ASTRONOMICAL) TIME OF THE CULMINATIONS AND ELONGATIONS OF POLARIS IN THE YEAR 1915

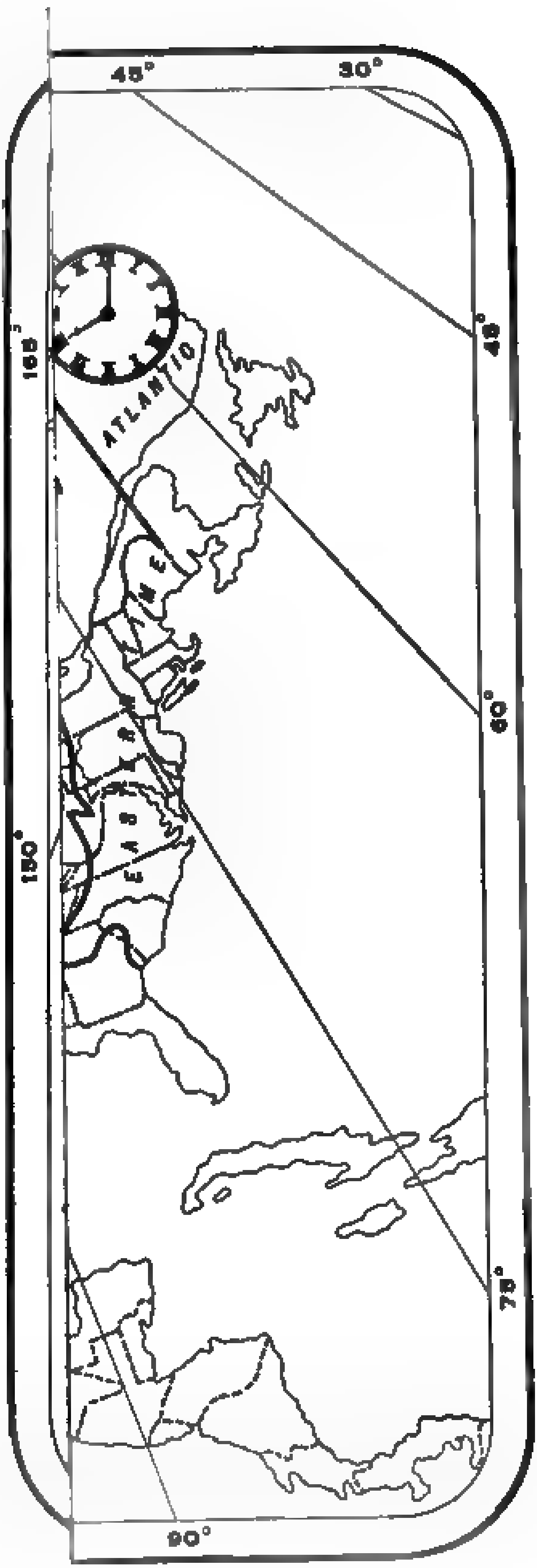
(Computed for latitude 40° north and longitude 90° or 6^h west of Greenwich)

Date	East Elongation		Upper Culmination		West Elongation		Lower Culmination	
1915	Hr.	Min.	Hr.	Min.	Hr.	Min.	Hr.	Min.
January 1	0	51.7	6	46.9	12	42.1	18	44.9
January 15	23	52.5	5	51.6	11	46.8	17	49.6
February 1	22	45.3	4	44.5	10	39.7	16	42.5
February 15	21	50.1	3	49.2	9	44.4	15	47.2
March 1	20	54.8	2	54.0	8	49.2	14	52.0
March 15	19	59.6	1	58.8	7	54.0	13	56.8
April 1	18	52.7	0	51.9	6	47.1	12	49.9
April 15	17	57.7	23	52.9	5	52.0	11	54.8
May 1	16	54.8	22	50.0	4	49.2	10	52.0
May 15	15	59.9	21	55.1	3	54.2	9	57.0
June 1	14	53.3	20	48.5	2	47.6	8	50.4
June 15	13	58.5	19	53.7	1	52.8	7	55.6
July 1	12	55.9	18	51.1	0	50.2	6	53.0
July 15	12	01.1	17	56.3	23	51.5	5	58.2
August 1	10	54.5	16	49.7	22	44.9	4	51.7
August 15	9	59.8	15	55.0	21	50.2	3	56.9
September 1	8	53.2	14	48.4	20	43.6	2	50.3
September 15	7	58.3	13	53.5	19	48.7	1	55.4
October 1	6	55.5	12	50.7	18	45.9	0	52.7
October 15	6	00.6	11	55.8	17	51.0	23	53.8
November 1	4	53.7	10	48.9	16	44.1	22	46.9
November 15	3	58.6	9	53.8	15	49.0	21	51.8
December 1	2	55.6	8	50.8	14	46.0	20	48.8
December 15	2	00.4	7	55.6	13	50.8	19	53.6

A. To refer the above tabular quantities to years other than 1915.

For year 1919	add	2.5 minutes
1920	add	4.0 up to March 1
	add	0.1 on and after March 1
1921	add	1.6
1922	add	3.1
1923	add	4.5
1924	add	5.9 up to March 1
	add	2.0 on and after March 1
1925	add	3.3
1926	add	4.6
1927	add	5.9
1928	add	7.2 up to March 1
	add	3.3 on and after March 1

B. To refer to any calender day other than the first and fifteenth of each month SUBTRACT *the quantities below from the tabular quantity for the* PRECEDING DATE.



45°
30°
45°
60°
75°
90°
165°
150°
ATLANTIC

TABLE 33.—LOCAL MEAN (ASTRONOMICAL) TIME OF THE CULMINATIONS AND ELONGATIONS OF POLARIS IN THE YEAR 1915

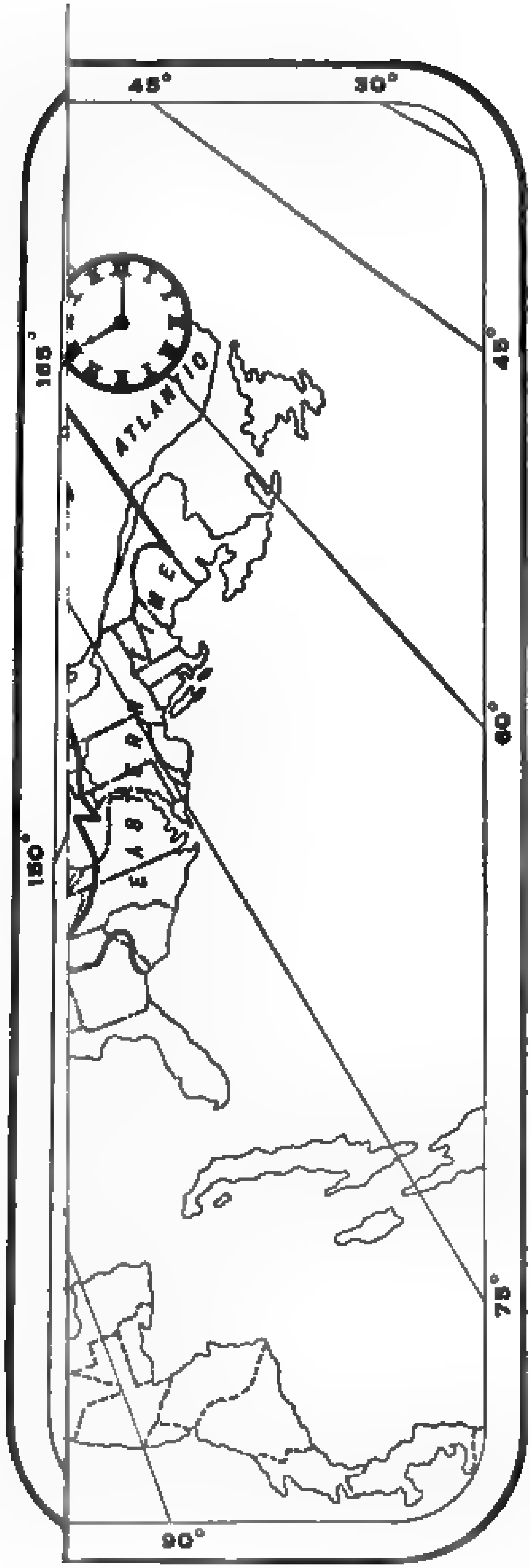
(Computed for latitude 40° north and longitude 90° or 6^h west of Greenwich)

Date	East Elongation		Upper Culmination		West Elongation		Lower Culmination	
1915	Hr.	Min.	Hr.	Min.	Hr.	Min.	Hr.	Min.
January 1	0	51.7	6	46.9	12	42.1	18	44.9
January 15	23	52.5	5	51.6	11	46.8	17	49.6
February 1	22	45.3	4	44.5	10	39.7	16	42.5
February 15	21	50.1	3	49.2	9	44.4	15	47.2
March 1	20	54.8	2	54.0	8	49.2	14	52.0
March 15	19	59.6	1	58.8	7	54.0	13	56.8
April 1	18	52.7	0	51.9	6	47.1	12	49.9
April 15	17	57.7	23	52.9	5	52.0	11	54.8
May 1	16	54.8	22	50.0	4	49.2	10	52.0
May 15	15	59.9	21	55.1	3	54.2	9	57.0
June 1	14	53.3	20	48.5	2	47.6	8	50.4
June 15	13	58.5	19	53.7	1	52.8	7	55.6
July 1	12	55.9	18	51.1	0	50.2	6	53.0
July 15	12	01.1	17	56.3	23	51.5	5	58.2
August 1	10	54.5	16	49.7	22	44.9	4	51.7
August 15	9	59.8	15	55.0	21	50.2	3	56.9
September 1	8	53.2	14	48.4	20	43.6	2	50.3
September 15	7	58.3	13	53.5	19	48.7	1	55.4
October 1	6	55.5	12	50.7	18	45.9	0	52.7
October 15	6	00.6	11	55.8	17	51.0	23	53.8
November 1	4	53.7	10	48.9	16	44.1	22	46.9
November 15	3	58.6	9	53.8	15	49.0	21	51.8
December 1	2	55.6	8	50.8	14	46.0	20	48.8
December 15	2	00.4	7	55.6	13	50.8	19	53.6

A. To refer the above tabular quantities to years other than 1915.

For year 1919	add	2.5 minutes	
1920	add	4.0 up to March 1	
	add	0.1 on and after March 1	
1921	add	1.6	
1922	add	3.1	
1923	add	4.5	
1924	add	5.9 up to March 1	
	add	2.0 on and after March 1	
1925	add	3.3	
1926	add	4.6	
1927	add	5.9	
1928	add	7.2 up to March 1	
	add	3.3 on and after March 1	

B. To refer to any calender day other than the first and fifteenth of each month SUBTRACT *the quantities below from the tabular quantity for the* PRECEDING DATE.



45°
30°
45°
60°
75°
90°
165°
150°
ATLANTIC

TABLE 34.—AZIMUTH OF POLARIS WHEN AT ELONGATION FOR ANY YEAR BETWEEN 1918 AND 1928

Latitude	1918	1919	1920	1921	1922	1923	1924	1925	1926	1927	1928
°	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′	° ′
10	1 09.0	1 08.7	1 08.4	1 08.1	1 07.8	1 07.4	1 07.2	1 06.8	1 06.5	1 06.2	1 05.9
11	09.2	08.9	08.6	08.3	08.0	07.7	07.4	07.0	06.7	06.4	06.1
12	09.5	09.2	08.9	08.6	08.2	07.9	07.6	07.3	07.0	06.7	06.4
13	09.8	09.4	09.1	08.8	08.5	08.2	07.8	07.6	07.2	06.9	06.6
14	10.0	09.7	09.4	09.1	08.8	08.5	08.2	07.8	07.5	07.2	06.9
15	10.4	10.0	09.7	09.4	09.1	08.8	08.5	08.1	07.8	07.5	07.2
16	10.7	10.4	10.1	09.8	09.4	09.1	08.8	08.5	08.2	07.8	07.5
17	11.1	10.8	10.4	10.1	09.8	09.5	09.2	08.8	08.5	08.2	07.9
18	11.5	11.1	10.7	10.5	10.2	09.8	09.5	09.2	08.9	08.6	08.2
19	11.9	11.6	11.2	10.9	10.6	10.2	09.9	09.6	09.3	09.0	08.6
20	12.3	12.0	11.7	11.4	11.0	10.7	10.4	10.0	09.7	09.4	09.1
21	12.8	12.5	12.2	11.8	11.5	11.2	10.8	10.5	10.2	09.8	09.5
22	13.3	13.0	12.6	12.3	12.0	11.6	11.3	11.0	10.6	10.3	10.0
23	13.8	13.5	13.2	12.8	12.5	12.2	11.8	11.5	11.2	10.8	10.5
24	14.4	14.1	13.7	13.4	13.0	12.7	12.4	12.0	11.7	11.4	11.0
25	15.0	14.7	14.3	14.0	13.6	13.3	13.0	12.6	12.3	11.9	11.6
26	15.6	15.3	14.9	14.7	14.2	13.9	13.6	13.2	12.9	12.5	12.2
27	16.3	15.9	15.6	15.2	14.9	14.6	14.2	13.9	13.5	13.2	12.8
28	17.0	16.6	16.3	15.9	15.6	15.2	14.9	14.6	14.2	13.8	13.5
29	17.7	17.4	17.0	16.6	16.3	16.0	15.6	15.2	14.9	14.6	14.2
30	18.5	18.1	17.8	17.4	17.0	16.7	16.4	16.0	15.6	15.3	14.9
31	19.3	18.9	18.6	18.2	17.9	17.5	17.2	16.8	16.4	16.1	15.7
32	20.1	19.8	19.4	19.1	18.7	18.3	18.0	17.6	17.2	16.9	16.5
33	21.0	20.7	20.3	19.9	19.6	19.2	18.8	18.5	18.1	17.8	17.4
34	22.0	21.6	21.2	20.9	20.5	20.1	19.8	19.4	19.0	18.6	18.3

35	23.0	22.6	22.2	21.8	21.5	21.1	20.7	20.4	20.0	19.6	19.2
36	24.0	23.6	23.3	22.9	22.5	22.1	21.7	21.4	21.0	20.6	20.2
37	25.1	24.7	24.3	24.0	23.6	23.2	22.8	22.4	22.0	21.6	21.3
38	26.2	25.9	25.5	25.1	24.7	24.3	23.9	23.5	23.2	22.8	22.4
39	27.5	27.1	26.7	26.3	25.8	25.5	25.1	24.7	24.3	23.9	23.5
40	28.7	28.3	27.9	27.5	27.1	26.7	26.3	25.9	25.5	25.1	24.7
41	30.0	29.6	29.1	28.8	28.4	28.0	27.6	27.2	26.8	26.4	26.0
42	31.5	31.0	30.6	30.2	29.8	29.4	29.0	28.6	28.2	27.8	27.3
43	32.9	32.5	32.1	31.8	31.2	30.8	30.4	30.0	29.6	29.1	28.7
44	34.5	34.1	33.6	33.2	32.8	32.4	31.9	31.5	31.1	30.6	30.2
45	36.1	35.7	35.3	34.8	34.4	34.0	33.5	33.1	32.6	32.2	31.8
46	37.8	37.4	37.0	36.5	36.1	35.6	35.2	34.8	34.3	33.9	33.4
47	39.7	39.2	38.8	38.3	37.9	37.4	37.0	36.5	36.1	35.6	35.2
48	41.6	41.1	40.7	40.2	39.8	39.3	38.8	38.4	37.9	37.4	37.0
49	43.6	43.1	42.7	42.2	41.7	41.3	40.8	40.3	39.9	39.4	38.9
50	1 45.7	1 45.3	1 44.8	1 44.3	1 43.8	1 43.4	1 42.9	1 42.4	1 41.9	1 41.4	1 41.0

Table No. 34 was computed with the mean declination of Polaris for each year. A more accurate result will be had by applying to the tabular values the following correction, which depend on the difference of the mean and the apparent place of the star. The deduced azimuth will, in general, be correct within 0′.3.

For Middle of	Correction	For Middle of	Correction
	′		′
January	−0.5	July	+0.2
February	−0.4	August	+0.1
March	−0.3	September	−0.1
April	0.0	October	−0.4
May	+0.1	November	−0.6
June	+0.2	December	−0.8

II.—To Determine the True Meridian by Observation on Polaris at Elongation with a Plumb Line and Peep Sight

"1. Attach the plumb line to a support situated as far above the ground as practicable, such as the limb of a tree, a piece of board nailed or otherwise fastened to a telegraph pole, a house, barn, or other building affording a clear view in a north and south direction.

"The plumb bob may consist of any weighty material, such as a brick, or a piece of iron or stone, weighing 4 to 5 pounds, which will hold the plumb line straight and vertical fully as well as one of turned and finished metal.

"Strongly illuminate the plumb line just below its support by a lamp or candle, care being taken to obscure the source of light from the view of the observer by an opaque screen.

"For a peep sight, cut a slot about one-sixteenth of an inch wide in a thin piece of board, or nail two strips of tin, with straight edges, to a square block of wood, so arranged that they will stand vertical when the block is placed flat on its base upon a smooth horizontal rest, which will be placed at a convenient height south of the plumb line and firmly secured in an east and west direction, in such a position that when viewed through the peep sight Polaris will appear about a foot below the support of the plumb line.

"The position may be determined by trial the night preceding that set for the observation.

"About thirty minutes before the time of elongation, as given in the tables of elongation, bring the peep sight into the same line of sight with the plumb line and Polaris.

"To reach elongation the star will move off the plumb line to the east for eastern elongation, or to the west for western elongation; therefore by moving the peep sight in the proper direction, east or west, as the case may be, keep the star on the plumb line until it appears to remain stationary, thus indicating that it has reached its point of elongation.

"The peep sight will now be secured in place by a clamp or weight, and all further operations will be deferred until the next morning.

"By daylight place a slender rod at a distance of 200 or 300 feet from the peep sight and exactly in range with it and the plumb line; carefully measure this distance.

"Take from the Table 34 the azimuth of Polaris corresponding to the latitude of the station and year of observation; find the natural tangent of said azimuth and multiply it by the distance from the peep sight to the rod; the product will express the distance to be laid off from the rod *exactly at right angles* to the direction already determined (to the *west* for eastern elongation or to the *east* for western elongation) to a point which with the peep sight will define the direction of the *true meridian* with a fair degree of accuracy."

To Determine the True Meridian by Means of an Observation of Polaris at Any Hour when the Star is Visible, the Correct Local Mean Time Being Known[1]

"This method requires a knowledge of the local mean time within one or two minutes, as in the extreme case when Polaris is at culmination its azimuth changes 1′ (arc) in 2½ minutes (time). The Standard time can usually be obtained at a telegraph office from the signals which are sent out from observatories. From this the local mean time may be derived by subtracting four minutes of time for every degree of longitude west of the Standard meridian or adding four minutes for every degree east of the Standard meridian. The local mean time may be obtained also by observations of the sum, one method being explained later.

"The following table, 35, is intended to be used in connection with the American Ephemeris and Nautical Almanac. The surveyor should read carefully the chapter in that publication in which the formation and use of the Ephemeris are explained, especially the portion defining the different kinds of time.

"The following example explains the use of the table and the derivation of the hour angle of Polaris:"

Position, latitude 36° 20′ N., longitude 80° 07′.5 or $5^h\ 20^m\ 30^s$ W. of Greenwich.

	h.	m.	s.	
Time of observation, July 10, 1908, standard (75th mer.) mean time	8	52	40	p. m.
Reduction to local time (5° 07′ west of 75th mer.)	−	20	30	
Local mean time	8	32	10	
Reduction to sidereal time (Table III, Amer. Ephem.)	+	01	24	
Sidereal time mean noon, Greenwich, July 10, 1902	7	12	02	
Correction for longitude $5^h\ 20^m\ 30^s$ (Table III, Amer. Ephem.)	+	00	53	
Local sidereal time	15	46	29	
Apparent right ascension of Polaris, July 10, 1908	1	26	05	
Hour angle before upper culmination	9	39	36	

[1] *cf.* Appendix No. 10, Coast and Geodetic Survey Report for 1895.

	°	′	
Declination for which Table 35 applies....	88	51	
Apparent declination, July 10, 1908.....	88	48.7	
Decrease in declination............	−	2.3	
	°	′	″
Azimuth from Table 35 (interpolated)...	0	48	39
Correction for 2′.3 decrease in declination.	+	1	37
Computed azimuth................	0	50	16 East of north.

"It is to be remembered that Polaris is east of the meridian for twelve hours before, and west of the meridian for twelve hours after, upper culmination.

"Without the American Ephemeris the table may be conveniently used for obtaining the true meridian, in connection with Table 33 giving the approximate mean times of culminations of Polaris, and the additional knowledge of the fact that the mean declination of Polaris is 88° 51′.1 in 1915 and increasing at the rate of about 0′.3 per year. Without the use of the Ephemeris the computation would be as follows:

	h.	m.	s.	
Time of observation, July 10, 1908 standard (75th mer.) mean time..................................	8	52	40	p. m.
Reduction to local mean time..........................	−	20	30	
Local mean time..............................	8	32	10	
Local mean time of upper culmination of Polaris (Table 33 and A)..................................	18	10	12	
Mean time of observation before upper culmination	9	38	02	
Reduction to sidereal time.........................	+	01	35	
Hour angle before upper culmination	9	39	37	

	°	′	
Declination for which Table 35 applies...	88	51.0	
Mean declination, 1908...............	88	49.0	
Decrease in declination............	−	2.0	
	°	′	″
Azimuth from Table 35...............	0	48	40
Correction for 2′.0 decrease in declination.	+	1	24
Computed azimuth...............	0	50	04 East of north.

Tables are generally given in books on surveying for reducing mean solar to sidereal time, but for this computation it is near enough to consider the correction 10ˢ an hour, as the stars gain very nearly four minutes on the Sun each day."[1]

Solar Meridian by Direct Observation with an Ordinary Transit.—Where the method of Polaris at elongation is not used, Direct Solar Observation is the most convenient method of meridian determination as while it involves more computation and introduces more chances of error the work can be done during daylight hours and the accuracy that can be attained (within 01′ of arc) with the usual facilities is close enough for all practical purposes of ordinary surveys.

[1] The sidereal correction always increases the hour angle.

There are a number of different forms of the fundamental formulæ governing the determination; the following form has found considerable favor:

$$\tan^2 \tfrac{1}{2}A = \frac{\sin[S-(90^\circ-\text{alt.})]\sin[S-(90^\circ-\text{lat.})]}{\sin S\sin[S-(90^\circ-\text{dec.})]}.$$

In the formula A is the angle of the sun from the true north measured to the right in the morning and to the left in the afternoon.

S is one-half the sum of (90° − the observed altitude of the sun corrected for refraction) plus (90° − the latitude of the point of observation) plus (90° − the declination of the sun at the time of observation).

NOTE.—Notice carefully the sign of the declination. A south declination is *a* − declination which would make the expression (90° − (− south declination)) = 90° + south declination.

A solar ephemeris from which the sun's declination is found is necessary for the computations. All instrument makers publish small pocket editions each year which can be obtained from them for ten cents.

An ordinary well regulated watch set for standard time at the nearest telegraph office serves for the time determination on which the sun's declination depends and any good transit with vertical circle can be used for observing the horizontal angle and altitude of the sun but observers are cautioned that it must be in good adjustment and the observer must work with reasonable care.

If standard time is not available mean local time can be determined by observation as explained later on page 413.

The latitude of the point of observation can generally be determined closely enough from U. S. Geological Survey Maps or Land Office Maps and if these are not available can be determined by observation as explained on page 413.

Longitude for standard time correction can be taken from any good map. If these are not available determine local mean time by observation.

Considering all the different sources of error, time, latitude and observed altitude the best time of day to make the observation is between 9.00 and 10.00 A. M. and between 2.00 and 3.00 P. M.

(*Continued page* 412.)

Table 35.—Azimuth of Polaris at Any Hour Angle

Hour Angle Before or After Upper Culmination	Azimuth of Polaris Computed for Declination 88° 51′											Correction for 1′ Increase in Declination of Polaris	
	Latitude 10°	Latitude 11°	Latitude 12°	Latitude 13°	Latitude 14°	Latitude 15°	Latitude 16°	Latitude 17°	Latitude 18°	Latitude 19°	Latitude 20°	Latitude 10°	Latitude 20°
h m	° ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′ ″	″	″
0 15	0 04 36	0 04 37	0 04 38	0 04 39	0 04 41	0 04 42	0 04 43	0 04 45	0 04 47	0 04 48	0 04 50	− 4	− 4
0 30	0 09 11	0 09 13	0 09 15	0 09 17	0 09 20	0 09 23	0 09 25	0 09 29	0 09 32	0 09 36	0 09 39	− 8	− 8
0 45	0 13 43	0 13 46	0 13 49	0 13 53	0 13 57	0 14 01	0 14 05	0 14 10	0 14 15	0 14 20	0 14 26	−12	−13
1 00	0 18 12	0 18 16	0 18 20	0 18 25	0 18 30	0 18 35	0 18 41	0 18 47	0 18 54	0 19 01	0 19 09	−16	−17
1 15	0 22 36	0 22 41	0 22 46	0 22 52	0 22 58	0 23 05	0 23 12	0 23 20	0 23 28	0 23 37	0 23 46	−20	−21
1 30	0 26 54	0 27 00	0 27 06	0 27 13	0 27 21	0 27 29	0 27 37	0 27 46	0 27 56	0 28 07	0 28 18	−24	−25
1 45	0 31 05	0 31 12	0 31 19	0 31 27	0 31 36	0 31 45	0 31 55	0 32 06	0 32 17	0 32 29	0 32 42	−27	−29
2 00	0 35 09	0 35 16	0 35 24	0 35 33	0 35 43	0 35 53	0 36 04	0 36 16	0 36 29	0 36 43	0 36 57	−31	−32
2 15	0 39 03	0 39 11	0 39 20	0 39 30	0 39 41	0 39 52	0 40 04	0 40 18	0 40 32	0 40 47	0 41 03	−34	−36
2 30	0 42 47	0 42 56	0 43 06	0 43 17	0 43 28	0 43 41	0 43 54	0 44 09	0 44 24	0 44 40	0 44 58	−37	−39
2 45	0 46 19	0 46 29	0 46 40	0 46 52	0 47 04	0 47 18	0 47 32	0 47 48	0 48 04	0 48 22	0 48 41	−40	−42
3 00	0 49 40	0 49 51	0 50 02	0 50 15	0 50 28	0 50 42	0 50 58	0 51 15	0 51 33	0 51 52	0 52 12	−43	−45
3 15	0 52 48	0 52 59	0 53 11	0 53 24	0 53 39	0 53 54	0 54 11	0 54 28	0 54 47	0 55 07	0 55 29	−46	−48
3 30	0 55 43	0 55 54	0 56 07	0 56 21	0 56 36	0 56 52	0 57 09	0 57 28	0 57 47	0 58 09	0 58 31	−49	−51
3 45	0 58 22	0 58 34	0 58 48	0 59 02	0 59 18	0 59 35	0 59 53	1 00 12	1 00 33	1 00 55	1 01 18	−51	−53
4 00	1 00 47	1 01 00	1 01 13	1 01 28	1 01 44	1 02 02	1 02 21	1 02 41	1 03 02	1 03 25	1 03 49	−53	−55
4 15	1 02 56	1 03 09	1 03 23	1 03 38	1 03 55	1 04 13	1 04 33	1 04 53	1 05 15	1 05 39	1 06 04	−55	−57
4 30	1 04 49	1 05 02	1 05 17	1 05 33	1 05 50	1 06 08	1 06 28	1 06 49	1 07 12	1 07 36	1 08 02	−56	−59
4 45	1 06 25	1 06 39	1 06 53	1 07 10	1 07 27	1 07 46	1 08 06	1 08 28	1 08 51	1 09 15	1 09 42	−58	−61
5 00	1 07 44	1 07 58	1 08 13	1 08 29	1 08 47	1 09 06	1 09 26	1 09 48	1 10 12	1 10 37	1 11 03	−59	−62
5 15	1 08 46	1 08 59	1 09 15	1 09 31	1 09 49	1 10 08	1 10 29	1 10 51	1 11 15	1 11 40	1 12 07	−60	−62
5 30	1 09 30	1 09 43	1 09 59	1 10 15	1 10 33	1 10 52	1 11 13	1 11 35	1 11 59	1 12 25	1 12 52	−60	−63
5 45	1 09 56	1 10 09	1 10 25	1 10 41	1 10 59	1 11 18	1 11 39	1 12 01	1 12 25	1 12 51	1 13 18	−61	−63

6 00	1 10 04	1 10 17	1 10 32	1 10 49	1 11 07	1 11 26	1 11 47	1 12 09	1 12 33	1 12 58	1 13 26	−61	−64
6 15	1 09 54	1 10 07	1 10 22	1 10 39	1 10 55	1 11 15	1 11 36	1 11 58	1 12 22	1 12 47	1 13 14	−61	−63
6 30	1 09 26	1 09 39	1 09 54	1 10 10	1 10 28	1 10 46	1 11 07	1 11 29	1 11 52	1 12 17	1 12 44	−60	−63
6 45	1 08 40	1 08 53	1 09 08	1 09 23	1 09 41	1 09 59	1 10 19	1 10 41	1 11 04	1 11 29	1 11 55	−60	−62
7 00	1 07 37	1 07 50	1 08 05	1 08 19	1 08 36	1 08 54	1 09 14	1 09 35	1 09 58	1 10 22	1 10 47	−59	−61
7 15	1 06 16	1 06 29	1 06 42	1 06 57	1 07 14	1 07 32	1 07 51	1 08 11	1 08 33	1 08 57	1 09 22	−58	−60
7 30	1 04 39	1 04 51	1 05 04	1 05 19	1 05 35	1 05 52	1 06 10	1 06 30	1 06 52	1 07 15	1 07 39	−56	−58
7 45	1 02 44	1 02 56	1 03 09	1 03 23	1 03 38	1 03 55	1 04 13	1 04 32	1 04 53	1 05 15	1 05 39	−54	−56
8 00	1 00 34	1 00 45	1 00 58	1 01 11	1 01 26	1 01 42	1 01 59	1 02 18	1 02 38	1 02 59	1 03 22	−52	−55
8 15	0 58 09	0 58 19	0 58 31	0 58 44	0 58 58	0 59 13	0 59 30	0 59 47	1 00 06	1 00 27	1 00 49	−50	−53
8 30	0 55 28	0 55 38	0 55 49	0 56 02	0 56 15	0 56 29	0 56 45	0 57 02	0 57 20	0 57 39	0 58 00	−48	−50
8 45	0 52 33	0 52 43	0 52 53	0 53 05	0 53 18	0 53 31	0 53 46	0 54 02	0 54 19	0 54 37	0 54 57	−45	−48
9 00	0 49 25	0 49 33	0 49 44	0 49 55	0 50 07	0 50 19	0 50 33	0 50 48	0 51 04	0 51 21	0 51 40	−42	−45
9 15	0 46 05	0 46 13	0 46 22	0 46 32	0 46 43	0 46 55	0 47 08	0 47 21	0 47 36	0 47 52	0 48 09	−40	−42
9 30	0 42 32	0 42 40	0 42 48	0 42 57	0 43 07	0 43 18	0 43 30	0 43 43	0 43 57	0 44 11	0 44 27	−37	−38
9 45	0 38 49	0 38 56	0 39 03	0 39 12	0 39 21	0 39 31	0 39 42	0 39 53	0 40 06	0 40 19	0 40 33	−34	−35
10 00	0 34 56	0 35 02	0 35 09	0 35 16	0 35 24	0 35 33	0 35 43	0 35 53	0 36 04	0 36 16	0 36 29	−31	−31
10 15	0 30 54	0 30 59	0 31 05	0 31 12	0 31 19	0 31 27	0 31 35	0 31 44	0 31 54	0 32 05	0 32 16	−28	−28
10 30	0 26 44	0 26 48	0 26 54	0 26 59	0 27 06	0 27 12	0 27 20	0 27 28	0 27 36	0 27 45	0 27 55	−24	−24
10 45	0 22 27	0 22 31	0 22 35	0 22 40	0 22 45	0 22 51	0 22 57	0 23 04	0 23 11	0 23 18	0 23 27	−20	−20
11 00	0 18 04	0 18 08	0 18 11	0 18 15	0 18 19	0 18 24	0 18 29	0 18 34	0 18 40	0 18 46	0 18 52	−16	−16
11 15	0 13 37	0 13 40	0 13 42	0 13 45	0 13 48	0 13 52	0 13 56	0 14 00	0 14 04	0 14 09	0 14 13	−12	−12
11 30	0 09 07	0 09 08	0 09 10	0 09 12	0 09 14	0 09 16	0 09 19	0 09 22	0 09 25	0 09 28	0 09 31	− 8	− 8
11 45	0 04 34	0 04 35	0 04 36	0 04 37	0 04 38	0 04 39	0 04 40	0 04 41	0 04 43	0 04 44	0 04 46	− 4	− 4
Elongation: Azimuth.......	1 10 04	1 10 18	1 10 33	1 10 49	1 11 07	1 11 26	1 11 47	1 12 09	1 12 33	1 12 58	1 13 26	−61	−64
	h m s	*h m s*	*h m s*	*h m s*	*h m s*	*h m s*	*h m s*	*h m s*	*h m s*	*h m s*	*h m s*	*s*	*s*
Hour angle......	5 59 11	5 59 06	5 59 02	5 58 56	5 58 51	5 58 46	5 58 41	5 58 36	5 58 30	5 58 25	5 58 19	+ 2	+ 2

TABLE 35.—AZIMUTH OF POLARIS AT ANY HOUR ANGLE—*continued*

Hour Angle Before or After Upper Culmination	Azimuth of Polaris Computed for Declination 88° 51′											Correction for 1′ Increase in Declination of Polaris	
	Latitude 20°	Latitude 21°	Latitude 22°	Latitude 23°	Latitude 24°	Latitude 25°	Latitude 26°	Latitude 27°	Latitude 28°	Latitude 29°	Latitude 30°	Latitude 20°	Latitude 30°
h m	° ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′ ″	″	″
0 15	0 04 50	0 04 52	0 04 55	0 04 57	0 04 59	0 05 02	0 05 04	0 05 07	0 05 10	0 05 13	0 05 17	− 4	− 5
0 30	0 09 39	0 09 43	0 09 48	0 09 52	0 09 57	0 10 02	0 10 07	0 10 13	0 10 19	0 10 25	0 10 31	− 8	− 9
0 45	0 14 26	0 14 32	0 14 38	0 14 45	0 14 52	0 15 00	0 15 07	0 15 16	0 15 25	0 15 34	0 15 44	−13	−14
1 00	0 19 09	0 19 16	0 19 25	0 19 34	0 19 43	0 19 53	0 20 04	0 20 15	0 20 26	0 20 39	0 20 51	−17	−18
1 15	0 23 46	0 23 56	0 24 07	0 24 18	0 24 29	0 24 42	0 24 55	0 25 08	0 25 23	0 25 38	0 25 54	−21	−23
1 30	0 28 18	0 28 29	0 28 42	0 28 55	0 29 09	0 29 24	0 29 39	0 29 55	0 30 12	0 30 30	0 30 49	−25	−27
1 45	0 32 42	0 32 55	0 33 10	0 33 25	0 33 41	0 33 58	0 34 16	0 34 34	0 34 54	0 35 15	0 35 37	−29	−31
2 00	0 36 57	0 37 12	0 37 29	0 37 46	0 38 04	0 38 23	0 38 43	0 39 04	0 39 26	0 39 50	0 40 15	−32	−35
2 15	0 41 03	0 41 20	0 41 38	0 41 57	0 42 17	0 42 38	0 43 00	0 43 24	0 43 49	0 44 14	0 44 42	−36	−39
2 30	0 44 58	0 45 16	0 45 36	0 45 57	0 46 19	0 46 42	0 47 06	0 47 32	0 47 59	0 48 27	0 48 57	−39	−43
2 45	0 48 41	0 49 01	0 49 22	0 49 45	0 50 08	0 50 33	0 51 00	0 51 27	0 51 57	0 52 27	0 53 00	−42	−46
3 00	0 52 12	0 52 33	0 52 56	0 53 20	0 53 45	0 54 12	0 54 40	0 55 10	0 55 41	0 56 14	0 56 48	−45	−50
3 15	0 55 29	0 55 51	0 56 15	0 56 41	0 57 08	0 57 36	0 58 06	0 58 37	0 59 10	0 59 45	1 00 22	−48	−53
3 30	0 58 31	0 58 55	0 59 20	0 59 47	1 00 15	1 00 45	1 01 16	1 01 49	1 02 24	1 03 01	1 03 40	−51	−56
3 45	1 01 18	1 01 43	1 02 09	1 02 37	1 03 07	1 03 38	1 04 11	1 04 46	1 05 22	1 06 00	1 06 41	−53	−58
4 00	1 03 40	1 04 15	1 04 43	1 05 13	1 05 42	1 06 15	1 06 49	1 07 25	1 08 02	1 08 42	1 09 24	−55	−61
4 15	1 06 04	1 06 31	1 06 59	1 07 29	1 08 01	1 08 34	1 09 09	1 09 46	1 10 25	1 11 06	1 11 49	−57	−63
4 30	1 08 02	1 08 29	1 08 58	1 09 29	1 10 01	1 10 35	1 11 12	1 11 50	1 12 30	1 13 12	1 13 56	−59	−64
4 45	1 09 42	1 10 10	1 10 39	1 11 10	1 11 44	1 12 19	1 12 55	1 13 34	1 14 15	1 14 58	1 15 44	−61	−66
5 00	1 11 03	1 11 32	1 12 02	1 12 34	1 13 07	1 13 43	1 14 20	1 15 00	1 15 41	1 16 25	1 17 11	−62	−68
5 15	1 12 07	1 12 36	1 13 06	1 13 38	1 14 12	1 14 48	1 15 26	1 16 06	1 16 48	1 17 32	1 18 19	−62	−69
5 30	1 12 52	1 13 21	1 13 51	1 14 24	1 14 58	1 15 34	1 16 13	1 16 53	1 17 35	1 18 20	1 19 07	−63	−69
5 45	1 13 18	1 13 47	1 14 18	1 14 50	1 15 25	1 16 01	1 16 39	1 17 19	1 18 02	1 18 47	1 19 34	−63	−69

6 00	1 13 26	1 13 54	1 14 25	1 14 57	1 15 32	1 16.08	1 16 46	1 17 26	1 18 09	1 18 53	1 19 41	−64	−70
6 15	1 13 14	1 13 43	1 14 13	1 14 45	1 15 19	1 15 55	1 16 33	1 17 13	1 17 55	1 18 40	1 19 26	−63	−69
6 30	1 12 44	1 13 12	1 13 42	1 14 14	1 14 48	1 15 23	1 16 01	1 16 40	1 17 22	1 18 06	1 18 52	−63	−68
6 45	1 11 55	1 12 23	1 12 52	1 13 24	1 13 57	1 14 32	1 15 09	1 15 48	1 16 29	1 17 12	1 17 58	−62	−67
7 00	1 10 47	1 11 15	1 11 44	1 12 15	1 12 47	1 13 22	1 13 58	1 14 36	1 15 16	1 15 59	1 16 44	−61	−66
7 15	1 09 22	1 09 49	1 10 17	1 10 47	1 11 19	1 11 53	1 12 28	1 13 05	1 13 45	1 14 26	1 15 10	−60	−65
7 30	1 07 39	1 08 05	1 08 32	1 09 02	1 09 33	1 10 05	1 10 40	1 11 16	1 11 54	1 12 35	1 13 17	−58	−64
7 45	1 05 39	1 06 04	1 06 30	1 06 59	1 07 28	1 08 00	1 08 33	1 09 08	1 09 46	1 10 24	1 11 06	−56	−62
8 00	1 03 22	1 03 46	1 04 11	1 04 38	1 05 07	1 05 38	1 06 10	1 06 43	1 07 19	1 07 57	1 08 36	−55	−60
8 15	1 00 49	1 01 11	1 01 36	1 02 02	1 02 30	1 02 59	1 03 29	1 04 02	1 04 36	1 05 12	1 05 49	−53	−57
8 30	0 58 00	0 58 22	0 58 45	0 59 10	0 59 36	1 00 04	1 00 33	1 01 04	1 01 36	1 02 10	1 02 46	−50	−54
8 45	0 54 57	0 55 17	0 55 40	0 56 03	0 56 28	0 56 54	0 57 22	0 57 51	0 58 21	0 58 53	0 59 27	−48	−51
9 00	0 51 40	0 51 59	0 52 20	0 52 41	0 53 04	0 53 29	0 53 55	0 54 22	0 54 51	0 55 21	0 55 53	−45	−48
9 15	0 48 09	0 48 27	0 48 46	0 49 07	0 49 28	0 49 51	0 50 15	0 50 40	0 51 07	0 51 35	0 52 05	−42	−45
9 30	0 44 27	0 44 43	0 45 01	0 45 20	0 45 40	0 46 01	0 46 22	0 46 46	0 47 11	0 47 37	0 48 04	−38	−42
9 45	0 40 33	0 40 48	0 41 04	0 41 21	0 41 39	0 41 58	0 42 19	0 42 40	0 43 02	0 43 26	0 43 51	−35	−38
10 00	0 36 29	0 36 43	0 36 57	0 37 12	0 37 29	0 37 46	0 38 04	0 38 23	0 38 43	0 39 04	0 39 27	−31	−34
10 15	0 32 16	0 32 28	0 32 41	0 32 54	0 33 08	0 33 24	0 33 40	0 33 57	0 34 14	0 34 34	0 34 53	−28	−30
10 30	0 27 55	0 28 05	0 28 16	0 28 28	0 28 40	0 28 53	0 29 07	0 29 22	0 29 37	0 29 53	0 30 10	−24	−26
10 45	0 23 27	0 23 35	0 23 44	0 23 54	0 24 05	0 24 16	0 24 27	0 24 39	0 24 52	0 25 06	0 25 20	−20	−22
11 00	0 18 52	0 18 59	0 19 07	0 19 15	0 19 23	0 19 32	0 19 41	0 19 51	0 20 01	0 20 12	0 20 24	−16	−18
11 15	0 14 13	0 14 19	0 14 24	0 14 30	0 14 37	0 14 43	0 14 50	0 14 58	0 15 05	0 15 14	0 15 22	−12	−13
11 30	0 09 31	0 09 34	0 09 38	0 09 42	0 09 46	0 09 51	0 09 56	0 10 01	0 10 06	0 10 11	0 10 17	− 8	− 9
11 45	0 04 46	0 04 48	0 04 50	0 04 52	0 04 54	0 04 56	0 04 58	0 05 00	0 05 03	0 05 06	0 05 09	− 4	− 4
Elongation: Azimuth......	1 13 26	1 13 55	1 14 25	1 14 58	1 15 32	1 16 08	1 16 46	1 17 27	1 18·09	1 18 54	1 19 41	−64	−69
	h m s	h m s	h m s	h m s	h m s	h m s	h m s	h m s	h m s	h m s	h m s	s	s
Hour angle......	5 58 19	5 58 14	5 58 08	5 58 03	5 57 57	5 57 51	5 57 45	5 57 39	5 57 33	5 57 27	5 57 21	+ 2	+ 2

TABLE 35.—AZIMUTH OF POLARIS AT ANY HOUR ANGLE—*continued*

Hour Angle Before or After Upper Culmination	Azimuth of Polaris Computed for Declination 88° 51′											Correction for 1′ Increase in Declination of Polaris	
	Latitude 30°	Latitude 31°	Latitude 32°	Latitude 33°	Latitude 34°	Latitude 35°	Latitude 36°	Latitude 37°	Latitude 38°	Latitude 39°	Latitude 40°	Latitude 30°	Latitude 40°
h m	° ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′ ″	″	″
0 15	0 05 17	0 05 20	0 05 23	0 05 27	0 05 31	0 05 35	0 05 40	0 05 44	0 05 49	0 05 54	0 06 00	−5	−5
0 30	0 10 31	0 10 38	0 10 45	0 10 53	0 11 01	0 11 09	0 11 18	0 11 27	0 11 37	0 11 47	0 11 57	−9	−10
0 45	0 15 44	0 15 54	0 16 04	0 16 16	0 16 27	0 16 40	0 16 53	0 17 07	0 17 21	0 17 36	0 17 52	−14	−16
1 00	0 20 51	0 21 05	0 21 19	0 21 34	0 21 50	0 22 05	0 22 24	0 22 42	0 23 01	0 23 21	0 23 42	−18	−21
1 15	0 25 54	0 26 11	0 26 28	0 26 47	0 27 06	0 27 27	0 27 48	0 28 11	0 28 34	0 28 59	0 29 26	−23	−26
1 30	0 30 49	0 31 09	0 31 30	0 31 52	0 32 15	0 32 40	0 33 05	0 33 32	0 34 00	0 34 30	0 35 01	−27	−31
1 45	0 35 37	0 36 00	0 36 24	0 36 49	0 37 16	0 37 44	0 38 14	0 38 44	0 39 17	0 39 51	0 40 27	−31	−36
2 00	0 40 15	0 40 41	0 41 08	0 41 37	0 42 07	0 42 38	0 43 12	0 43 47	0 44 23	0 45 02	0 45 42	−35	−40
2 15	0 44 42	0 45 11	0 45 41	0 46 13	0 46 46	0 47 21	0 47 58	0 48 37	0 49 18	0 50 00	0 50 45	−39	−45
2 30	0 48 57	0 49 29	0 50 02	0 50 37	0 51 13	0 51 52	0 52 32	0 53 14	0 53 59	0 54 46	0 55 35	−43	−49
2 45	0 53 00	0 53 34	0 54 10	0 54 47	0 55 27	0 56 08	0 56 52	0 57 37	0 58 25	0 59 16	1 00 09	−46	−53
3 00	0 56 48	0 57 25	0 58 03	0 58 43	0 59 25	1 00 10	1 00 56	1 01 45	1 02 37	1 03 31	1 04 28	−50	−57
3 15	1 00 22	1 01 01	1 01 41	1 02 24	1 03 08	1 03 55	1 04 45	1 05 37	1 06 31	1 07 29	1 08 29	−53	−60
3 30	1 03 40	1 04 20	1 05 03	1 05 48	1 06 35	1 07 24	1 08 16	1 09 11	1 10 08	1 11 09	1 12 12	−56	−63
3 45	1 06 41	1 07 23	1 08 08	1 08 54	1 09 44	1 10 35	1 11 30	1 12 27	1 13 27	1 14 30	1 15 36	−58	−66
4 00	1 09 24	1 10 08	1 10 54	1 11 43	1 12 34	1 13 28	1 14 24	1 15 23	1 16 26	1 17 31	1 18 40	−61	−69
4 15	1 11 49	1 12 35	1 13 23	1 14 13	1 15 06	1 16 01	1 16 59	1 18 00	1 19 05	1 20 12	1 21 23	−63	−72
4 30	1 13 56	1 14 43	1 15 32	1 16 23	1 17 18	1 18 14	1 19 14	1 20 17	1 21 23	1 22 32	1 23 45	−64	−74
4 45	1 15 44	1 16 31	1 17 21	1 18 14	1 19 09	1 20 07	1 21 08	1 22 12	1 23 20	1 24 31	1 25 45	−66	−75
5 00	1 17 11	1 18 00	1 18 51	1 19 44	1 20 40	1 21 39	1 22 41	1 23 46	1 24 55	1 26 07	1 27 23	−68	−76
5 15	1 18 19	1 19 08	1 19 59	1 20 54	1 21 50	1 22 50	1 23 53	1 24 59	1 26 08	1 27 21	1 28 38	−69	−77
5 30	1 19 07	1 19 56	1 20 48	1 21 42	1 22 40	1 23 40	1 24 43	1 25 49	1 26 59	1 28 12	1 29 30	−69	−78
5 45	1 19 34	1 20 23	1 21 15	1 22 10	1 23 07	1 24 08	1 25 11	1 26 17	1 27 27	1 28 41	1 29 58	−69	−78

6 00	1 19 41	1 20 30	1 21 22	1 22 16	1 23 13	1 24 14	1 25 17	1 26 23	1 27 33	1 28 47	1 30 04	−70	−78
6 15	1 19 26	1 20 15	1 21 07	1 22 01	1 22 58	1 23 58	1 25 01	1 26 07	1 27 17	1 28 30	1 29 46	−69	−78
6 30	1 18 52	1 19 41	1 20 32	1 21 26	1 22 22	1 23 21	1 24 24	1 25 29	1 26 38	1 27 50	1 29 06	−68	−77
6 45	1 17 58	1 18 46	1 19 36	1 20 29	1 21 25	1 22 23	1 23 24	1 24 29	1 25 37	1 26 48	1 28 03	−67	−76
7 00	1 16 44	1 17 31	1 18 20	1 19 12	1 20 06	1 21 04	1 22 04	1 23 07	1 24 14	1 25 24	1 26 37	−66	−75
7 15	1 15 10	1 15 56	1 16 44	1 17 35	1 18 28	1 19 24	1 20 23	1 21 25	1 22 30	1 23 38	1 24 50	−65	−73
7 30	1 13 17	1 14 02	1 14 49	1 15 38	1 16 30	1 17 24	1 18 21	1 19 21	1 20 25	1 21 31	1 22 41	−64	−72
7 45	1 11 06	1 11 49	1 12 34	1 13 22	1 14 12	1 15 05	1 16 00	1 16 58	1 17 59	1 19 04	1 20 11	−62	−69
8 00	1 08 36	1 09 18	1 10 01	1 10 47	1 11 36	1 12 26	1 13 20	1 14 16	1 15 14	1 16 16	1 17 21	−60	−66
8 15	1 05 49	1 06 29	1 07 11	1 07 55	1 08 41	1 09 30	1 10 21	1 11 14	1 12 11	1 13 10	1 14 12	−57	−64
8 30	1 02 46	1 03 24	1 04 04	1 04 46	1 05 29	1 06 16	1 07 04	1 07 55	1 08 49	1 09 45	1 10 44	−54	−61
8 45	0 59 27	1 00 03	1 00 40	1 01 20	1 02 01	1 02 45	1 03 31	1 04 19	1 05 10	1 06 03	1 06 59	−51	−58
9 00	0 55 53	0 56 26	0 57 02	0 57 39	0 58 18	0 58 59	0 59 43	1 00 27	1 01 14	1 02 04	1 02 57	−48	−54
9 15	0 52 05	0 52 36	0 53 09	0 53 43	0 54 20	0 54 58	0 55 38	0 56 20	0 57 04	0 57 50	0 58 39	−45	−50
9 30	0 48 04	0 48 33	0 49 03	0 49 35	0 50 08	0 50 43	0 51 20	0 51 58	0 52 39	0 53 22	0 54 07	−42	−46
9 45	0 43 51	0 44 17	0 44 44	0 45 13	0 45 44	0 46 16	0 46 49	0 47 24	0 48 01	0 48 40	0 49 21	−38	−42
10 00	0 39 27	0 39 50	0 40 15	0 40 41	0 41 08	0 41 37	0 42 07	0 42 39	0 43 12	0 43 47	0 44 24	−34	−38
10 15	0 34 53	0 35 14	0 35 35	0 35 58	0 36 22	0 36 48	0 37 14	0 37 42	0 38 12	0 38 43	0 39 15	−30	−34
10 30	0 30 10	0 30 28	0 30 47	0 31 07	0 31 28	0 31 50	0 32 12	0 32 37	0 33 02	0 33 29	0 33 57	−26	−29
10 45	0 25 20	0 25 35	0 25 51	0 26 08	0 26 25	0 26 43	0 27 03	0 27 23	0 27 44	0 28 07	0 28 30	−22	−24
11 00	0 20 24	0 20 36	0 20 49	0 21 02	0 21 16	0 21 31	0 21 46	0 22 03	0 22 20	0 22 38	0 22 57	−18	−20
11 15	0 15 22	0 15 31	0 15 41	0 15 51	0 16 02	0 16 13	0 16 24	0 16 37	0 16 50	0 17 03	0 17 17	−13	−15
11 30	0 10 17	0 10 23	0 10 29	0 10 36	0 10 43	0 10 51	0 10 58	0 11 07	0 11 15	0 11 24	0 11 34	− 9	−10
11 45	0 05 09	0 05 12	0 05 15	0 05 19	0 05 22	0 05 26	0 05 30	0 05 34	0 05 38	0 05 43	0 05 47	− 4	− 5
Elongation:													
Azimuth.......	1 19 41	1 20 30	1 21 22	1 22 17	1 23 14	1 24 14	1 25 18	1 26 24	1 27 34	1 28 48	1 30 05	−69	−78
	h m s	*h m s*	*h m s*	*h m s*	*h m s*	*h m s*	*h m s*	*h m s*	*h m s*	*h m s*	*h m s*	*s*	*s*
Hour angle......	5 57 21	5 57 14	5 57 08	5 57 01	5 56 54	5 56 47	5 56 39	5 56 32	5 56 24	5 56 16	5 56 08	+ 2	+ 3

Hour Angle Before or After Upper Culmination	Azimuth of Polaris Computed for Declination 88° 51′ Latitude 40°	Latitude 41°	Latitude 42°	Latitude 43°	Latitude 44°	Latitude 45°	Latitude 46°	Latitude 47°	Latitude 48°	Latitude 49°	Latitude 50°	Correction for 1′ Increase in Declination of Polaris Latitude 40°	Latitude 50°
h m	° ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′ ″	″	″
0 15	0 06 00	0 06 05	0 06 11	0 06 17	0 06 24	0 06 31	0 06 38	0 06 46	0 06 54	0 07 03	0 07 12	−5	−6
0 30	0 11 57	0 12 09	0 12 21	0 12 33	0 12 46	0 13 00	0 13 14	0 13 30	0 13 46	0 14 03	0 14 21	−10	−13
0 45	0 17 52	0 18 09	0 18 27	0 18 45	0 19 05	0 19 25	0 19 47	0 20 10	0 20 34	0 21 00	0 21 27	−16	−19
1 00	0 23 42	0 24 04	0 24 28	0 24 52	0 25 18	0 25 45	0 26 14	0 36 45	0 27 17	0 27 51	0 28 27	−21	−25
1 15	0 29 26	0 29 53	0 30 22	0 30 53	0 31 25	0 31 59	0 32 34	0 33 12	0 33 52	0 34 34	0 35 18	−26	−32
1 30	0 35 01	0 35 34	0 36 08	0 36 45	0 37 23	0 38 03	0 38 46	0 39 30	0 40 18	0 41 08	0 42 01	−31	−38
1 45	0 40 27	0 41 05	0 41 45	0 42 27	0 43 11	0 43 57	0 44 46	0 45 38	0 46 33	0 47 30	0 48 31	−36	−43
2 00	0 45 42	0 46 25	0 47 10	0 47 57	0 48 47	0 49 39	0 50 35	0 51 33	0 52 35	0 53 40	0 54 49	−40	−49
2 15	0 50 45	0 51 33	0 52 22	0 53 15	0 54 10	0 55 08	0 56 09	0 57 14	0 58 22	0 59 35	1 00 51	−45	−54
2 30	0 55 35	0 56 26	0 57 21	0 58 18	0 59 18	1 00 22	1 01 29	1 02 40	1 03 54	1 05 13	1 06 37	−49	−59
2 45	1 00 09	1 01 05	1 02 04	1 03 06	1 04 11	1 05 20	1 06 32	1 07 48	1 09 09	1 10 34	1 12 04	−53	−64
3 00	1 04 28	1 05 28	1 06 30	1 07 36	1 08 46	1 10 00	1 11 17	1 12 39	1 14 05	1 15 36	1 17 12	−57	−68
3 15	1 08 29	1 09 32	1 10 39	1 11 49	1 13 03	1 14 21	1 15 43	1 17 10	1 18 41	1 20 18	1 22 00	−60	−72
3 30	1 12 12	1 13 19	1 14 29	1 15 43	1 17 00	1 18 22	1 19 49	1 21 20	1 22 56	1 24 37	1 26 25	−63	−76
3 45	1 15 36	1 16 46	1 17 59	1 19 16	1 20 37	1 22 03	1 23 33	1 25 08	1 26 49	1 28 35	1 30 27	−66	−80
4 00	1 18 40	1 19 52	1 21 08	1 22 28	1 23 53	1 25 21	1 26 54	1 28 34	1 30 18	1 32 08	1 34 05	−69	−83
4 15	1 21 23	1 22 38	1 23 56	1 25 19	1 26 46	1 28 17	1 29 54	1 31 33	1 33 24	1 35 17	1 37 17	−72	−86
4 30	1 23 45	1 25 02	1 26 22	1 27 47	1 29 16	1 30 50	1 32 30	1 34 14	1 36 06	1 38 01	1 40 04	−74	−88
4 45	1 25 45	1 27 03	1 28 26	1 29 52	1 31 23	1 32 59	1 34 41	1 36 28	1 38 20	1 40 19	1 42 25	−75	−90
5 00	1 27 23	1 28 42	1 30 06	1 31 34	1 33 06	1 34 44	1 36 27	1 38 16	1 40 10	1 42 11	1 44 19	−76	−91
5 15	1 28 38	1 29 58	1 31 23	1 32 52	1 34 25	1 36 04	1 37 48	1 39 38	1 41 34	1 43 36	1 45 45	−77	−92
5 30	1 29 30	1 30 50	1 32 16	1 33 45	1 35 20	1 36 59	1 38 44	1 40 34	1 42 31	1 44 34	1 46 44	−78	−93
5 45	1 29 58	1 31 20	1 32 45	1 34 15	1 35 50	1 37 29	1 39 14	1 41 05	1 43 02	1 45 05	1 47 16	−78	−94

6 00	1 30 04	1 31 25	1 32 50	1 34 20	1 35 55	1 37 34	1 39 19	1 41 09	1 43 06	1 45 09	1 47 19	−78	−93
6 15	1 29 46	1 31 07	1 32 32	1 34 01	1 35 35	1 37 14	1 38 58	1 40 48	1 42 44	1 44 46	1 46 56	−78	−93
6 30	1 29 06	1 30 26	1 31 50	1 33 18	1 34 51	1 36 29	1 38 12	1 40 01	1 41 56	1 43 57	1 46 04	−77	−92
6 45	1 28 03	1 29 20	1 30 44	1 32 11	1 33 43	1 35 19	1 37 01	1 38 48	1 40 41	1 42 40	1 44 46	−76	−91
7 00	1 26 37	1 27 54	1 29 15	1 30 41	1 32 11	1 33 45	1 35 25	1 37 10	1 39 01	1 40 58	1 43 02	−75	−89
7 15	1 24 50	1 26 05	1 27 24	1 28 48	1 30 16	1 31 48	1 33 25	1 35 08	1 36 56	1 38 51	1 40 51	−73	−87
7 30	1 22 41	1 23 54	1 25 11	1 26 32	1 27 58	1 29 27	1 31 02	1 32 42	1 34 27	1 36 18	1 38 16	−72	−85
7 45	1 20 11	1 21 22	1 22 36	1 23 55	1 25 17	1 26 44	1 28 16	1 29 52	1 31 34	1 33 22	1 35 15	−69	−82
8 00	1 17 21	1 18 29	1 19 41	1 20 57	1 22 16	1 23 40	1 25 08	1 26 41	1 28 19	1 30 02	1 31 51	−66	−79
8 15	1 14 12	1 15 17	1 16 26	1 17 38	1 18 54	1 20 14	1 21 39	1 23 07	1 24 41	1 26 20	1 28 05	−64	−76
8 30	1 10 44	1 11 46	1 12 52	1 14 00	1 15 12	1 16 29	1 17 49	1 19 14	1 20 43	1 22 17	1 23 56	−61	−72
8 45	1 06 59	1 07 57	1 08 59	1 10 04	1 11 12	1 12 23	1 13 40	1 15 00	1 16 24	1 17 53	1 19 27	−58	−68
9 00	1 02 57	1 03 52	1 04 50	1 05 50	1 06 55	1 08 02	1 09 13	1 10 28	1 11 47	1 13 10	1 14 38	−54	−64
9 15	0 58 39	0 59 30	1 00 24	1 01 21	1 02 20	1 03 23	1 04 29	1 05 39	1 06 52	1 08 10	1 09 32	−50	−59
9 30	0 54 07	0 54 54	0 55 44	0 56 36	0 57 31	0 58 28	0 59 29	1 00 34	1 01 41	1 02 53	1 04 08	−46	−55
9 45	0 49 21	0 50 04	0 50 49	0 51 37	0 52 27	0 53 20	0 54 15	0 55 13	0 56 15	0 57 20	0 58 29	−42	−50
10 00	0 44 24	0 45 02	0 45 43	0 46 25	0 47 10	0 47 58	0 48 47	0 49 40	0 50 35	0 51 34	0 52 35	−38	−45
10 15	0 39 15	0 39 49	0 40 25	0 41 03	0 41 42	0 42 24	0 43 08	0 43 54	0 44 43	0 45 35	0 46 29	−34	−40
10 30	0 33 57	0 34 26	0 34 57	0 35 30	0 36 04	0 36 40	0 37 18	0 37 58	0 38 40	0 39 24	0 40 12	−29	−34
10 45	0 28 30	0 28 55	0 29 21	0 29 48	0 30 17	0 30 47	0 31 19	0 31 53	0 32 28	0 33 05	0 33 45	−24	−29
11 00	0 22 57	0 23 16	0 23 37	0 23 59	0 24 22	0 24 47	0 25 12	0 25 39	0 26 08	0 26 38	0 27 09	−20	−23
11 15	0 17 17	0 17 32	0 17 48	0 18 05	0 18 22	0 18 40	0 19 00	0 19 20	0 19 42	0 20 04	0 20 28	−15	−18
11 30	0 11 34	0 11 44	0 11 54	0 12 06	0 12 17	0 12 29	0 12 42	0 12 56	0 13 10	0 13 25	0 13 43	−10	−12
11 45	0 05 47	0 05 52	0 05 58	0 06 04	0 06 09	0 06 15	0 06 22	0 06 29	0 06 36	0 06 44	0 06 51	− 5	− 6
Elongation: Azimuth.......	1 30 05	1 31 26	1 32 51	1 34 21	1 35 56	1 37 35	1 39 20	1 41 11	1 43 08	1 45 11	1 47 21	−78	−93
	h m s	*h m s*	*h m s*	*h m s*	*h m s*	*h m s*	*h m s*	*h m s*	*h m s*	*h m s*	*h m s*	*s*	*s*
Hour angle......	5 56 08	5 56 00	5 55 51	5 55 43	5 55 33	5 55 24	5 55 14	5 55 04	5 54 53	5 54 42	5 54 31	+ 3	+ 3

The following table gives the correction for observed altitude due to atmospheric refraction. This correction is always minus as the sun always appears to be higher than it actually is.

A TABLE OF MEAN REFRACTIONS DUE TO ALTITUDE
Bar. 30 in., Ther. 50°F.

App. Alt.	Ref.	App. Alt.	Ref.	App. Alt.	Ref.	App. Alt.	Ref.
5°	9′ 46″	10°	5′ 16″	20°	2′ 37″	50°	0′ 48″
6°	8′ 23″	12°	4′ 25″	25°	2′ 03″	60°	0′ 33″
7°	7′ 20″	14°	3′ 47″	30°	1′ 40″	70°	0′ 21″
8°	6′ 30″	16°	3′ 19″	35°	1′ 22″	80°	0′ 10″
9°	5′ 49″	18°	2′ 56″	40°	1′ 09″	90°	0′ 0″

A TABLE OF SEMI-DIAMETERS OF THE SUN

Jan. 1, 16′18″	Apr. 1, 16′02″	July 1, 15′46″	Oct. 1, 16′01″
Feb. 1, 16′16″	May 1, 15′54″	Aug. 1, 15′48″	Nov. 1, 16′09″
Mar. 1, 16′10″	June 1, 15′48″	Sept. 1, 15′53″	Dec. 1, 16′15″

Effect of Errors in Latitude and Declination on Meridian Determination.—It is well to bear in mind the effect of wrong latitude, or time (which affects the declination), on your meridian computations.

The following table prepared by Professor J. B. Johnson of Washington University, St. Louis, Mo., reprinted in the Metro Manual of the Bausch & Lomb Optical Co. shows the effect of error in latitude and declination for different latitudes and different hours in the day.

ERRORS IN AZIMUTH (BY SOLAR OBSERVATION) FOR 1 MINUTE ERRORS IN DECLINATION AND LATITUDE.

Hour	For 1 Min. Error in Declination				For 1 Min. Error in Latitude			
	Lat. 30°	Lat. 40°	Lat. 50°	Lat. 60°	Lat. 30°	Lat. 40°	Lat. 50°	Lat. 60°
	Min.	Min.	Min.	Min.	Min.	Min.	Min.	Min.
11.30 A. M. / 12.30 P. M.	8.85	10.00	11.92	14.07	8.87	9.92	11.82	13.56
11.00 A. M. / 1.00 P. M.	4.46	5.04	6.01	7.68	4.31	4.87	5.81	6.37
10.00 A. M. / 2.00 P. M.	2.31	2.61	3.11	4.00	2.00	2.26	2.69	3.46
9.00 A. M. / 3.00 P. M.	1.63	1.85	2.20	2.83	1.15	1.31	1.56	2.00
8.00 A. M. / 4.00 P. M.	1.33	1.51	1.80	2.31	0.67	0.75	0.90	1.15
7.00 A. M. / 5.00 P. M.	1.20	1.35	1.61	2.07	0.31	0.35	0.42	0.54
6.00 A. M. / 6.00 P. M.	1.15	1.31	1.56	2.00	0.00	0.00	0.00	0.00

Stated simply this means that if the observations are taken between 9 and 10 o'clock as recommended that for the most unfavorable conditions of fast changing declination an error of time of 15 minutes will result in an error of 01′ of arc on the meridian computations.

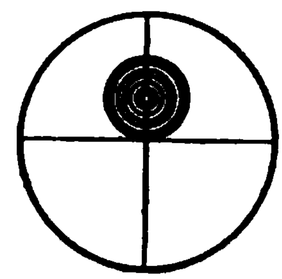
It is well to check the latitude by observation unless your location is well fixed on a very reliable map. A simple method of latitude determination is quoted from the Metro Manual of the Bausch & Lomb Optical Co.

LATITUDE DETERMINATIONS

"Latitude may be variously determined by observing the transit of a star, by a mean altitude of polaris or by a direct observation on the altitude of the sun at apparent noon.

"Owing to the earth's annual motion in its orbit, the sun changes his position along the ecliptic with respect to the stars at a not altogether uniform rate; so that some solar days are either longer or shorter than others.

"For the reason that a chronometer could not conveniently be made to change its speed to suit this solar phenomenon, there has been established a uniform system of time called "mean solar time." The difference between mean noon, when the sun should be on the meridian, and apparent noon when the sun actually is on the meridian, is called the "Equation of Time." The tabular corrections will be found in the Ephemeris Tables.



"Thus, in early November the sun has passed the meridian more than 16 min. before mean noon. It is always well to begin latitude observations some 20 min. before local noon, although there will be seasons of the year when the sun will not attain its greatest altitude until after local noon.

"**Standard time** will also qualify the argument, but this should be studied out by reference to the map on page 396. In Western Texas, for instance, observations need not begin until nearly 1 o'clock standard time; whereas in Erie, Pa., they should begin shortly after 11.

"**Procedure.**—Follow up the lower limb of the sun, and when the maximum altitude is found add the sun's semi-diameter, as given on page 412, to the reading on the vertical circle; subtract correction for atmospheric refraction, as figured by interpolation from the table, page 412, and correct this result by the sun's declination: adding if south and subtracting if north. The final result is the co-latitude or the polar distance (90° − latitude)."

To find the latitude subtract the co-latitude from 90°, *i.e.*, latitude = 90° − co-latitude.

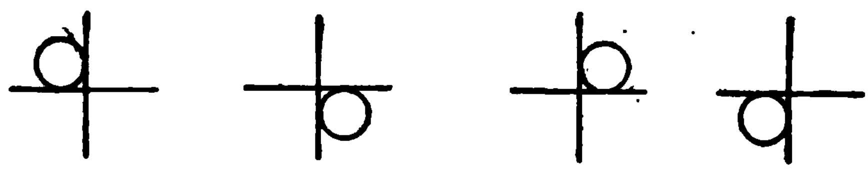
Time.—In case telegraphic standard time is not available determine the meridian by polaris at elongation and then the mean local time can be obtained by the transit of polaris across the meridian by referring to Table 33, page 396 or by the apparent sun time

when it crosses the Meridian at noon connected to Mean time as given in the Ephemeris referred to on page 403 which can be obtained from any instrument maker.

SOLAR MERIDIAN BY DIRECT OBSERVATION, PROCEDURE AND EXAMPLE OF COMPUTATION

Procedure.—An ordinary transit with ½ vertical circle in good adjustment will give satisfactory results although it is convenient to have a machine with a full vertical circle and a masked prismatic eyepiece for direct observation.

When using an ordinary transit remove the cap from the eyepiece and then by focusing the eyepiece and objective lenses correctly a sharp well-defined image of both cross wires and sun can be projected onto a piece of white paper held a few inches back of the eyepiece. The vertical and horizontal angles to the sun can then be read by bringing the image of the sun tangent to the image of the vertical and horizontal wires simultaneously and the time recorded. Two, four or six observations are made as rapidly as possible with the image of the sun alternately in opposite quadrants and the average time, average vertical angle and average horizontal angle used in the computations.



Observation No.1., No.2., No.3., No.4.

Example.—Solar meridian observations at Lima, Ohio, Jan. 18, 1918.

Average time of 4 observations, 2.42 P. M. Central Standard time.

Average horizontal angle (mark to sun)......		132° 22′ 00″
Average vertical angle to sun...............		16° 37′ 00″
Longitude of Lima...........................		84° 07′ 00″
Latitude of Lima............................		40° 45′ 00″
Observed altitude of sun....................		16° 37′ 00″
Refraction correction.......................		— 3′ 00″
Corrected altitude..........................		16° 34′ 00″
Latitude....................................		40° 45′ 00″
Declination at time of observation..........	S.	20° 34′ 30″

Declination Computation.—Observed standard time (central 90th meridian) 2.42 P. M. Lima is 5° 33′ east of the 90th meridian. To get the correct local mean time add to the recorded time 4 minutes for each degree of longitude east of the 90th meridian or 4 × 5.9° = 23.6 minutes. (Say 24 minutes.)

Correct local mean time of observation 3.06 P. M.

Take from the Ephemeris the sun's declination at Greenwich mean noon of Jan. 18, 1918 = S. 20° 38.9'.

Lima is 84° 07' west of Greenwich or its mean local time is 5 hours and 36 minutes earlier. That is the local mean time of Lima at Greenwich mean noon is 6.24 A. M. and the sun's declination for 6.24 A. M. Lima local mean time is S. 20° 38.9'.

The declination is decreasing at the rate of 30" per hour. The time of observation 3.06 P. M. local mean time is 8 hours and 42 minutes later than 6.24 A. M. and the declination for the time of observation is therefore:

Declination at 6.24 A. M. Lima	= S. 20° 38.9'
8.7 hours × 0.5' (30" hourly change)	= — 4.3'
Declination at time of observation	= S. 20° 34.6'
	= S. 20° 34' 36"
Say	= S. 20° 34' 30"

It should be remembered that a south declination is a minus declination. Be careful of your signs in the following formula: Applying the formula

$$\tan^2 \tfrac{1}{2}A = \frac{\sin[S - (90° - \text{alt.})] \sin[S - (90° - \text{lat.})]}{\sin S \sin[S - (90° - \text{dec.})]}$$

$$S = \frac{(90° - 16° 34') + (90° - 40° 45') + (90° - (-20° 34' 30''))}{2}$$

$$S = \frac{73° 26' + 49° 15' + 110° 34' 30''}{2} = 116° 37' 45''$$

$$S - (90° - \text{alt.}) = 43° 11' 45''$$
$$S - (90° - \text{lat.}) = 67° 22' 45''$$
$$S - (90° - \text{dec.}) = 6° 03' 15''$$

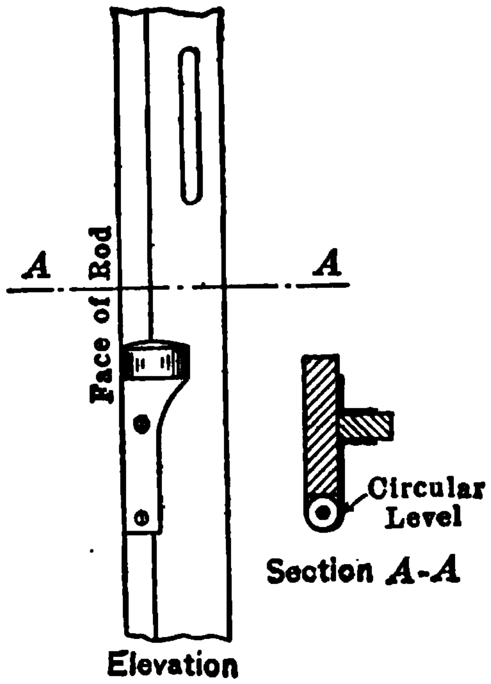
log sin 43° 11' 45"	= 9.835 3697
log sin 67° 22' 45"	= 9.965 2348
colog sin (180° − 116° 37' 45") 63° 22' 15"	= 0.048 6988
colog sin 6° 03' 15"	= 0.976 8768
log tan² ½A =	2|20.826 1801
log tan ½A =	0.413 0900
½A =	68° 52' 45"
A =	137° 45' 30"

As the observation was in the afternoon the angle between the sun and true north is 137° 45' 30" to the west of north. The azimuth from the instrument to the sun is therefore 360° − 137° 45' 30" = 222° 14' 30".

The true azimuth from the instrument to the mark is therefore 222° 14' 30" − 132° 22' = 89° 52' 30".

To mark the true meridian on the ground turn off an angle of 89° 52' 30" to the left from the reference mark used in the observation.

The Ross Meridiograph.—If much meridian work is being done it will pay to obtain the Ross Meridiograph which graphically solves the solar meridian to the nearest minute. It is quick and simple to use and eliminates the one drawback of the direct observation namely, the extended computations.

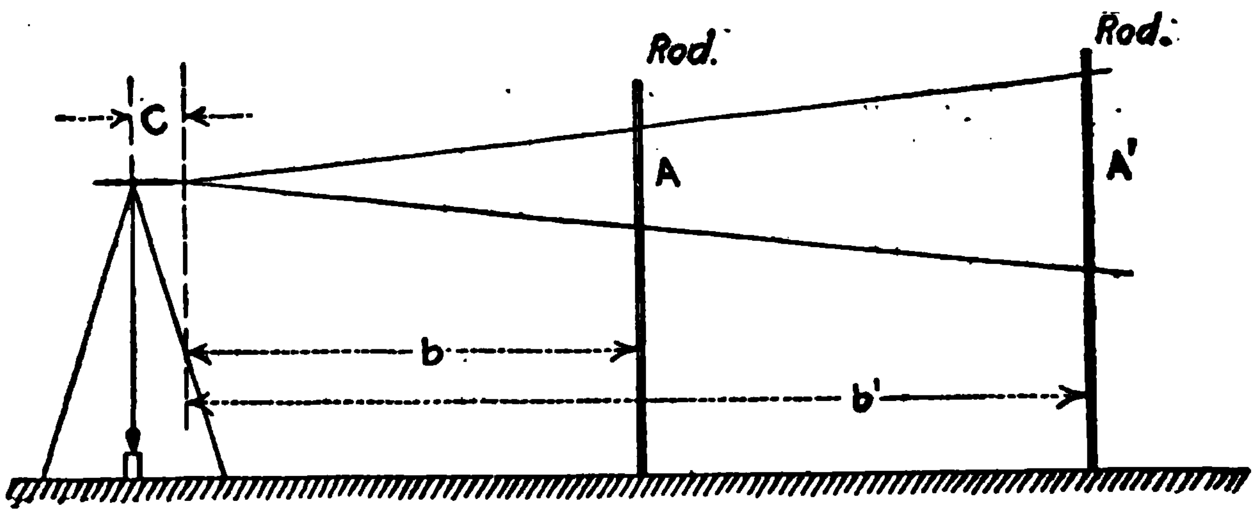


Sketch of circular plumbing level for stadia rods.

STADIA MEASUREMENTS

An expert instrumentman with a first-class transit can get more accurate results in rough country providing the atmospheric conditions are steady by the use of the stadia method of measurement than by the ordinary chaining of the average survey gang. The author has for a number of years worked under a restriction of a closure of less than 5.0 feet to the mile which is better than can be attained by ordinary chainmen in hard topography. The method is quick and reliable and is to be preferred in open country. Chaining is to be preferred in heavy cutting or where curves must be run in.

For an ordinary tangent preliminary survey the stadia method is very satisfactory. To get good results however, the observer should be expert. The ordinary garden variety of instrumentmen can not use stadia successfully; he should check his main line by both back and foresight readings. He must keep his instrument



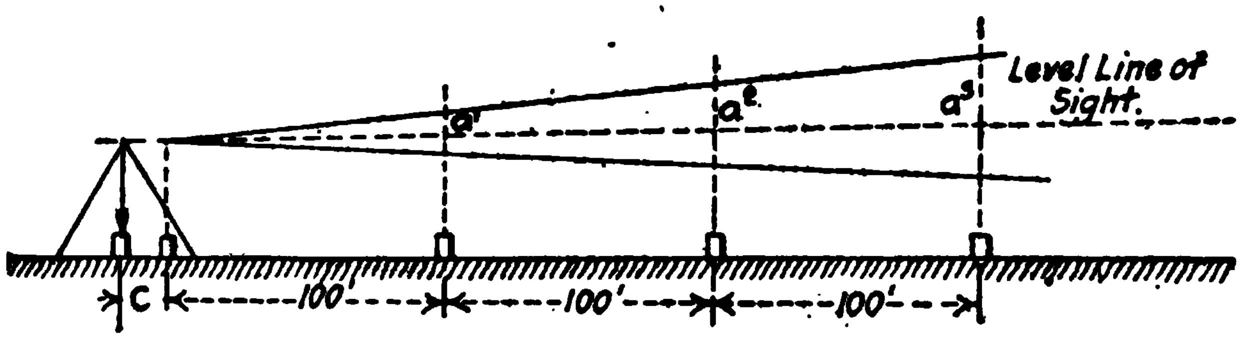
in first-class shape and must use a rod with a fairly broad face with clear distinctive markings; this rod must be held steady and vertical which can be accomplished by the use of a small universal circular level attached to the rod, and steadiness can be secured by a short hand rod (about 4′ long) that the rodman uses as a shifting brace.

The transit must be steady, must have a first-class lense and must be equipped with fixed stadia wires. Adjustable stadia

wires are worthless if good work is required. Distances between hubs should as a rule not exceed 500 to 600 feet for close line measurements but side slots can be taken up to 1500 feet.

The essential elements of the theory of stadia measurement are briefly as follows:

The measurement depends on the optical angle of the stadia wires. This angle is governed by the distance apart of the stadia wires. The rod intervals A and A' subtended between the stadia wires are directly proportional to the distances b and b' from the apex of the optical angle. The apex of this optical angle is always a certain fixed distance in front of the instrument and is different for different makes of transit. Call this distance C which can be determined as later explained by test or is generally noted in instructions furnished by the instrument maker. The actual rod interval as read by the observer is therefore proportional to the distance from a point ahead of the instrument and not from the center of the transit. For close work this distance C must be known and also the rod interval per 100 feet of distance beyond the apex of the optical angle. The rod interval per 100′ of distance



is desirably 1.0′ but unless unusual care is exercised in setting the wires it is rarely exactly this value. To determine the actual value of this interval proceed as follows:

Case 1.—Where the value of C is known.

(NOTE.—C generally ranges between 0.75′ and 1.25′.)

Pick out a level line about 800 to 1000′ long. Drive a transit hub; place a foresight picket. Measure from the transit hub toward the foresight the distance C which we will assume in this case to be 1.25′ and drive a hub. This hub represents on the ground the apex of the optical angle. From this hub measure carefully with a steel chain 100′ and set a hub on line with the foresight and continue to set points at intervals of exactly 100 feet until you have a test line 800 to 1000 feet long.

Now level the telescope and read the rod intervals when the rod is held on each of the stakes and record this interval to the nearest fraction of a foot that you are sure you can actually see. As the length of sight increases it becomes less and less possible to determine exactly the interval and when you are not certain of the reading to a 0.01′ stop attempting to lengthen the sight and you have practically determined the safe length of sight for actual line work that the instrument is capable of handling. To determine the rod interval record your readings and take the average value. Assume your rod intervals to be as follows:

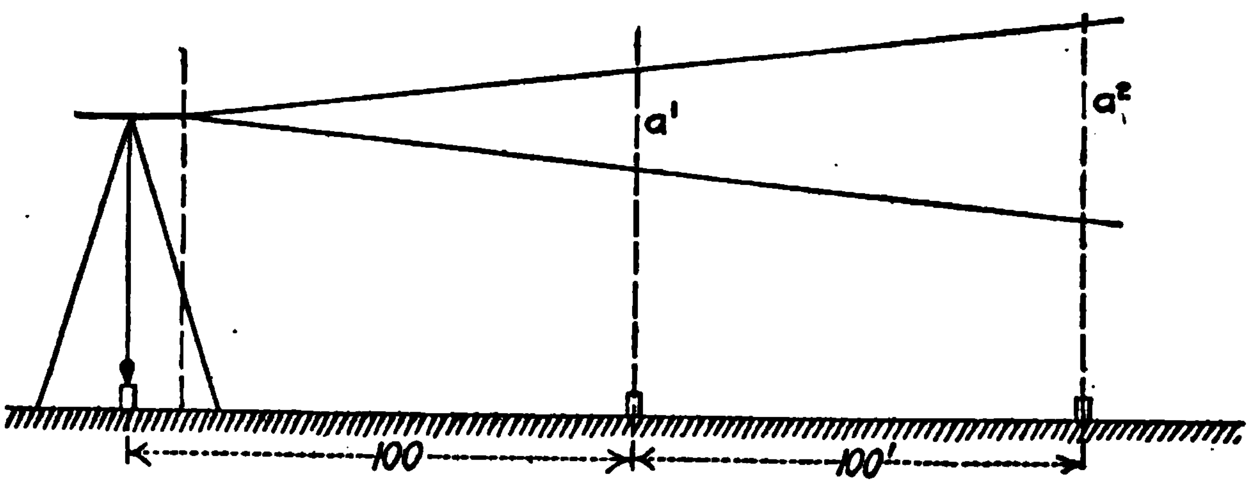
a^1..................	0.997 feet	$\div$ 1	= 0.997
a^2..................	1.995 "	$\div$ 2	= 0.9975
a^3..................	2.99 "	$\div$ 3	= 0.9967
a^4..................	3.99 "	$\div$ 4	= 0.9975
a^5..................	4.985 "	$\div$ 5	= 0.997
a^6..................	5.97 "	$\div$ 6	= 0.995
a^7..................	6.95 "	$\div$ 7	= 0.993
a^8..................	8.02 "	$\div$ 8	= 1.002

This indicates that beyond 500′ the readings become uncertain and that about 600′ is the limit of practical line sight for close work. Good stadia work requires that the instrumentman is perfectly honest with himself and recognizes his limitation when it is reached. The rod interval per 100′ is therefore 0.997 in this case and every foot on the rod *when the line of sight is level* means an actual distance from the apex of the optical angle of $\frac{1.000}{0.997}$ = 100.3 feet.

To get the actual distance then for a level line of sight rod reading of 2.45 feet multiply 2.45 × 100.3 = 245.73 feet.

Say 245.7 feet from the apex of the optical angle and the distance from the center of the instrument will be 245.7 feet plus the constant C (1.25) equals 246.95 feet from the center of the instrument.

The effect of the inclined line of sight will be discussed later.



Case 2.—Where the constant C is not known. To determine the constant C and the rod interval per 100′ of distance beyond the apex of the optical angle.

Measure a base line 800 to 1000′ long as previously stated placing hubs every 100′.

Set the transit up over the first hub and with a level line of sight read the stadia wire rod interval at each of the stakes on the line which are at actually measured known distances from the center of the instrument of 100′, 200′, 300′, etc.

The problem is to determine two unknown quantities, C the constant and X (the rod interval per 100 feet of distance beyond the apex of the optical angle). According to Case 1, $\frac{1.00 \text{ ft.}}{X}$ =

the actual distance beyond the apex represented by a rod interval of one foot. Therefore we can determine the constant C from two equations using the actual rod intervals a^1 and a^2 at the stakes which are 100′ and 200′ from the center of the instrument thus.

$$100' - C = \text{observed rod interval } a^1 \times \frac{1.00'}{X}$$

$$200' - C = \text{"} \quad \text{"} \quad \text{"} \quad a^2 \times \frac{1.00}{X}$$

Suppose the rod interval $a^1 = 0.9845$
" " " " $a^2 = 1.9815$

$$100.0 - C = 0.9845 \frac{1.00}{X}$$

$$200.0 - C = 1.9815 \frac{1.00}{X}.$$

call $\left(\frac{1.00}{X}\right)$ the symbol Y.

$$100.0 - C = 0.9845Y \qquad \text{Equation 1,}$$
$$200.0 - C = 1.9815Y \qquad \text{" } 2.$$

$$100.0 = 0.997\ Y \qquad \text{Subtract Equation 1 from 2.}$$

$$Y = \frac{100.00}{0.997}$$
$$Y = 100.3 \text{ feet.}$$

That is, a one foot rod interval equals 100.3′ of distance beyond the apex of the optical angle.

To determine C substitute this value of Y in Equation 1.

$$100.0 - C = 0.9845 \times 100.3$$
$$- C = - 100 + 98.75$$
$$C = 100 - 98.75$$
$$C = 1.25 \text{ feet.}$$

Apply this principle to three or four sets of readings and take the mean values.

You now have the basic constants of the instruments for close work.

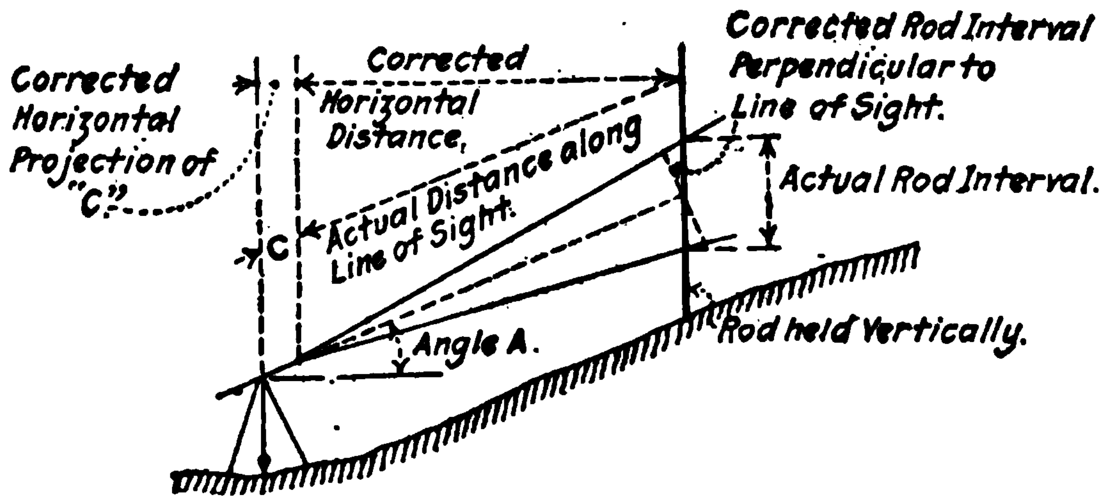
Effect of Inclined Sight on Stadia Readings.—The previous discussion is based on a level line of sight. It should be borne in mind that the stadia distance as previously discussed refers to the distance along the line of sight when the rod is perpendicular to the line of sight.

In case the line of sight is inclined the rod reading must be corrected to a true rod reading perpendicular to the inclined

line of sight and the distance along the inclined line of sight must be corrected to the true horizontal distance.

Rod interval × cos A (angle of inclination) = corrected rod interval.

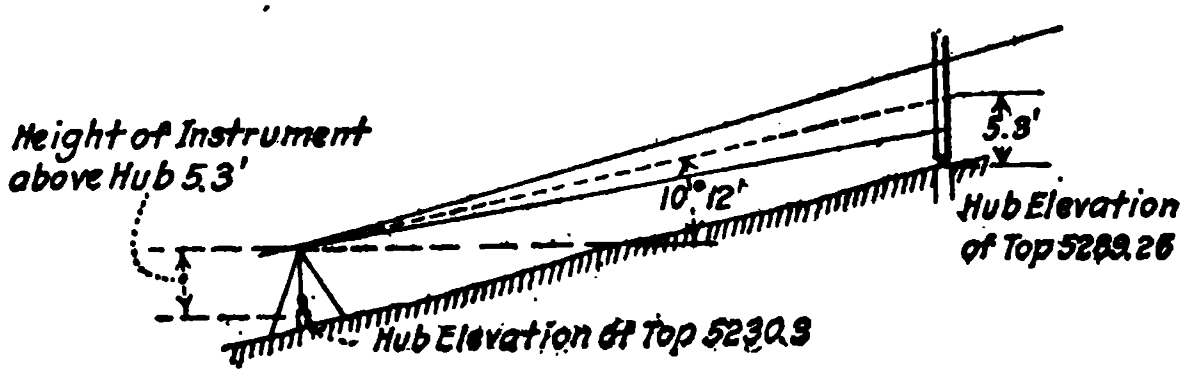
(Corrected rod interval in feet × actual distance value per foot as determined by test × cos angle A) + (the constant C × cos angle A) = corrected horizontal distance.



All standard stadia reduction tables and diagrams similar to Table 30, page 335, are based on (100 feet of distance for 1.0 of rod interval) plus the constant of the instrument.

If much stadia work is to be done all instrument makers will set fixed stadia wires guaranteed to measure 100′ distance per 1.0 of rod interval for the distance from the apex of the optical angle and such wires are generally sufficiently close to this standard so that for all practical survey work on which stadia methods are desirable no correction for rod interval need be applied.

The following example of reduction of stadia reading for careful line work will show the method.



Case 1.—Where the stadia wires are guaranteed to read 100′ distance per foot of rod interval and the constant C = 1.25 feet.

Procedure.—Measure the height of the center of the telescope axis at the standards above the top of the transit hub; this is called the Height of instrument. Assume this for example to be 5.3 feet.

To get the vertical angle to the next hub sight on the rod with the middle horizontal wire set on 5.3 feet on the rod held on the foresight hub and read the vertical angle say + 10° 13′: level the telescope by the large telescope bubble and record the index error say + 0° 01′: the correct vertical angle is then + 10° 12′.

To get the rod interval reading corresponding to the vertical

angle of $+10° 12'$ sight on the rod with the middle horizontal wire on $5.3'$: then shift the vertical line of sight so that the lower stadia wire is exactly on one of the main rod divisions and read the rod interval between the two stadia wires. Say in this case 3.37 feet or 337 feet distance. Look in Table 30, page 337, which gives for a vertical angle of $10° 12'$ the correct horizontal and vertical distance per $100'$ of stadia reading as horizontal distance $96.86'$; vertical difference in elevation $17.43'$. The total horizontal distance for the stadia reading of 337 feet is therefore $(337 \times 96.86 = 326.42) + (\text{constant } C \times \cos 10° 12')$ given at bottom of page in table as $1.23) = 327.65$ *total horizontal distance.*

The Vertical difference in elevation is $(337 \times 17.43' = 58.74') + ((\text{constant } C \times \sin 10° 12')$ given at bottom of page in Table 30 as $0.22) = 58.96'$ total difference in elevation. The elevation of the new hub is therefore $5230.3 + 58.96 = 5289.26$.

Case 2.—Where a stadia interval must be corrected for poor wire interval.

Suppose the instrument used measures $100.3'$ for each foot on the rod and the rod reading for a vertical angle of $10° 12'$ is 3.36 feet. The correct stadia distance is found by multiplying 3.36 feet $\times$ $100.3 = 337$ feet in distance. Then proceed as in Case 1.

Stadia Rods.—Stadia rods can be divided in innumerable ways and it makes little difference what symbols are used so long as they are clear and distinct. The principle of bisection for the smallest readings is a good system. The face of the rods should be wider than the ordinary level rod; a width of 2½ to 3" is about right. They should have a very brilliant white background and jet black face markings with large numbers for the even feet marks *the tenths should not be numbered.*

The practice of special graduations to fit the wire interval of the instrument is not desirable particularly in rough country where rods are often broken.

A standard 1.0 ft. division is safer, as any standard rod can then be used.

The following system of face markings has been used by the author and is given merely as an example in case the reader has no preference of his own.

The rods should be as light as possible with a back brace to prevent warping and provide hand holes and a length of $10'$ is ample for all practical purposes.

TABLE 35.—AZIMUTH OF POLARIS AT ANY HOUR ANGLE—*continued*

Hour Angle Before or After Upper Culmination	Azimuth of Polaris Computed for Declination 88° 51′											Correction for 1′ Increase in Declination of Polaris	
	Latitude 40°	Latitude 41°	Latitude 42°	Latitude 43°	Latitude 44°	Latitude 45°	Latitude 46°	Latitude 47°	Latitude 48°	Latitude 49°	Latitude 50°	Latitude 40°	Latitude 50°
h m	° ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′ ″	° ′ ″	″	″
0 15	0 06 00	0 06 05	0 06 11	0 06 17	0 06 24	0 06 31	0 06 38	0 06 46	0 06 54	0 07 03	0 07 12	−5	−6
0 30	0 11 57	0 12 09	0 12 21	0 12 33	0 12 46	0 13 00	0 13 14	0 13 30	0 13 46	0 14 03	0 14 21	−10	−13
0 45	0 17 52	0 18 09	0 18 27	0 18 45	0 19 05	0 19 25	0 19 47	0 20 10	0 20 34	0 21 00	0 21 27	−16	−19
1 00	0 23 42	0 24 04	0 24 28	0 24 52	0 25 18	0 25 45	0 26 14	0 36 45	0 27 17	0 27 51	0 28 27	−21	−25
1 15	0 29 26	0 29 53	0 30 22	0 30 53	0 31 25	0 31 59	0 32 34	0 33 12	0 33 52	0 34 34	0 35 18	−26	−32
1 30	0 35 01	0 35 34	0 36 08	0 36 45	0 37 23	0 38 03	0 38 46	0 39 30	0 40 18	0 41 08	0 42 01	−31	−38
1 45	0 40 27	0 41 05	0 41 45	0 42 27	0 43 11	0 43 57	0 44 46	0 45 38	0 46 33	0 47 30	0 48 31	−36	−43
2 00	0 45 42	0 46 25	0 47 10	0 47 57	0 48 47	0 49 39	0 50 35	0 51 33	0 52 35	0 53 40	0 54 49	−40	−49
2 15	0 50 45	0 51 33	0 52 22	0 53 15	0 54 10	0 55 08	0 56 09	0 57 14	0 58 22	0 59 35	1 00 51	−45	−54
2 30	0 55 35	0 56 26	0 57 21	0 58 18	0 59 18	1 00 22	1 01 29	1 02 40	1 03 54	1 05 13	1 06 37	−49	−59
2 45	1 00 09	1 01 05	1 02 04	1 03 06	1 04 11	1 05 20	1 06 32	1 07 48	1 09 09	1 10 34	1 12 04	−53	−64
3 00	1 04 28	1 05 28	1 06 30	1 07 36	1 08 46	1 10 00	1 11 17	1 12 39	1 14 05	1 15 36	1 17 12	−57	−68
3 15	1 08 29	1 09 32	1 10 39	1 11 49	1 13 03	1 14 21	1 15 43	1 17 10	1 18 41	1 20 18	1 22 00	−60	−72
3 30	1 12 12	1 13 19	1 14 29	1 15 43	1 17 00	1 18 22	1 19 49	1 21 20	1 22 56	1 24 37	1 26 25	−63	−76
3 45	1 15 36	1 16 46	1 17 59	1 19 16	1 20 37	1 22 03	1 23 33	1 25 08	1 26 49	1 28 35	1 30 27	−66	−80
4 00	1 18 40	1 19 52	1 21 08	1 22 28	1 23 53	1 25 21	1 26 54	1 28 34	1 30 18	1 32 08	1 34 05	−69	−83
4 15	1 21 23	1 22 38	1 23 56	1 25 19	1 26 46	1 28 17	1 29 54	1 31 33	1 33 24	1 35 17	1 37 17	−72	−86
4 30	1 23 45	1 25 02	1 26 22	1 27 47	1 29 16	1 30 50	1 32 30	1 34 14	1 36 06	1 38 01	1 40 04	−74	−88
4 45	1 25 45	1 27 03	1 28 26	1 29 52	1 31 23	1 32 59	1 34 41	1 36 28	1 38 20	1 40 19	1 42 25	−75	−90
5 00	1 27 23	1 28 42	1 30 06	1 31 34	1 33 06	1 34 44	1 36 27	1 38 16	1 40 10	1 42 11	1 44 19	−76	−91
5 15	1 28 38	1 29 58	1 31 23	1 32 52	1 34 25	1 36 04	1 37 48	1 39 38	1 41 34	1 43 36	1 45 45	−77	−92
5 30	1 29 30	1 30 50	1 32 16	1 33 45	1 35 20	1 36 59	1 38 44	1 40 34	1 42 31	1 44 34	1 46 44	−78	−93
5 45	1 29 58	1 31 20	1 32 45	1 34 15	1 35 50	1 37 29	1 39 14	1 41 05	1 43 02	1 45 05	1 47 16	−78	−94

CHAPTER XII

PHOTOGRAPHY, CAMP EQUIPMENT AND NOTES ON CAMP MEDICINE

EDITOR'S NOTE.—Photographs are often as important as survey notes particularly on reconnaissance work and the failure of a negative is comparable to the loss of field notes. The following data has been inserted to help the inexperienced photographer reduce his percentage of failures. A greenhand is puzzled chiefly by diaphram opening and time of exposure and does not understand the effect of latitude, altitude, time of year, light, etc., on the problem. The following simple notes have been prepared by a man who has taken Engineering Photographs all over the world and should be helpful. There are a number of very excellent exposure charts and mechanical sensitized paper exposure meters on the market which consider all these points in more detail than we can give in a book of this character.

NOTES ON PHOTOGRAPHY

General.—The following discussion of the subject of photography in connection with engineering operations has been prepared with the idea of giving to the engineer the foundations and principles upon which he may make exposures in the field under most all conditions, and secure fairly uniform results. The engineer is, in the day's work, required to make exposures under some very adverse conditions, and it is not rare that the exposure most needed or the most important point along the line of survey or construction is reached when weather and light conditions are at their worst. In many cases the results are failures, poor, or only fair. This fact, under the ordinary procedure of having the film developed after the point has been passed, or the survey completed, is discovered weeks or months afterward, and a return to the point would either be expensive—so much so as to make it prohibitive—or impossible on account of adverse weather conditions.

Views on preliminary surveys are of more importance and should receive corresponding attention. Views on construction and location are important, but the opportunities for making successful exposures on location and construction are many. This is due to the fact that the engineer is located longer at one camp on location than on preliminary, while on construction he is constantly on the job.

It is urged that all work be done in the field at the time of making the exposures on preliminary investigations or reconnaissance surveys in order that failures may be discovered and additional exposures made which will supply the omissions, and assure a continuity of views. By so doing the finished view may then and there be properly identified and notations made as to its value in

connection with the surveyed line, and the subsequent report and estimate, as explained on page 283. With this end in view the following equipment is suggested.

Equipment.

1. Camera with good stout leather case and tripod.
2. Tank developing outfit complete.
3. Films, chemicals, and paper sufficient of photograph length of the line.

This outfit has been used for a number of years by men who have had a wide experience, and it has been found to be a convenient and complete camp kit to properly care for the picture end of a survey.

Roughly the films should be estimated at three exposures to the mile of line.

Camera.—The best sized camera, that is, the one which produces the largest picture in proportion to the bulk of outfit and cost of operation, is the $4\frac{1}{4} \times 6\frac{1}{2}$ film camera—Eastman 4A. Cameras having smaller dimensions produce views so small as to be of little value from an engineering standpoint, while the outfit necessary to carry on development is practically the same in size and weight as that required for the camera above mentioned. Enlargements may be made, but this is an additional expense and delay. What is required is speed and accuracy.

This sized film when properly masked will give a picture $4\frac{1}{8}'' \times 6\frac{3}{8}''$ exclusive of legend. If the roll is cut so as to leave the unexposed portions between the exposures, on the bottom of vertical views, or the left hand end of horizontal views, space is left for filing number and legend. This information is put on the face of the film with india ink as soon as it is dry and is a clear but concise statement of (*a*) station from which the view was taken, (*b*) direction of the camera, (*c*) general description of features shown, or purpose for which taken, and (*d*) index number by which the same may be identified. This information is obtained from the exposure record which is made and kept at the time of the exposure, and regarding which description is given on page 430.

Autographic backed cameras are in use but are not specially desirable unless the films are to be developed by some other person at a latter date. The writing that may be done while specific, is generally so large as to take up all the space between the exposures which should be devoted to more detail. If used it is better to merely record the roll and exposure number as R 23-2 and depend on the exposure record for detail data.

Lens.—The camera should be equipped with a standard lens of known value. In the matter of lenses nothing empirical may be said. Generally, however, the regular B. & L. f 16 rectilinear lens gives excellent results. As speed is not essential the higher priced rapid lenses are not necessary, and the investment of money is such a refinement which the work in hand does not call for, is a luxury to say the least. Given a well made and flawless lens, an equally good picture may be secured, provided the proper time is given, as with the more expensive lens. As there are no moving

objects in the class of views that the engineer will photograph, exposures may be properly timed.

Shutter.—The shutter should be of the ordinary variety, operated or snapped with a bulb or cable. For rough handling the bulb release is considered the best. There are a number of standard shutters on the market, anyone of which gives entirely satisfactory results. Improvements are being continually made, and it is advisable to purchase the most durable pattern on the market. There is less liability of making errors with the shutter that sets and releases automatically with a bulb or cable. Those that have to be set by hand ofttimes produce no exposure, the photographer forgetting to set the shutter.

Diaphram.—Most all cameras are now equipped with the iris diaphram, and this attachment is the best with which to control the stop.

The stop is the technical term for regulating the size of opening in the diaphram. There are two systems of indicating the different stops. The "Universal Standard" (U. S.) and "f" for focal speed of lens. The following list shows the usual stops for both systems that are equal to each other.

U. S.	1.2	2.0	2.5	4	8	16	32	64
f	4.5	5.6	6.3	8	11	16	22	32
Ordinary kodak stops						1	2	3

Stop U. S. 1.2 gives the largest opening.
" " 64 " " smallest " .

Manipulation.—The most important factors that enter into making an exposure are:

1. Composition.
2. Distance.
3. Aperture.
4. Time.
5. Strength and direction of light.
6. Phases of views.
7. Recording all operations in the exposure record.

Taking up these operations in their order:

Composition.—A photo should not be looked upon as a miscellaneous lot of black and white spots on a piece of paper. In order that the photo should properly show the information required, it should in most instances be taken from some station along the line of work, or from some point which has been definitely located without the line of work. The most desirable position from which to make the exposure is one from which professional as well as artistic points may be seen. The selection of such a point is made after carefully studying the composition of the view as seen in the finder. If a view is required along the survey line, select if possible, that station where the light will come from behind or from the side. Carefully study the composition.

If on a survey line, along a stream bank, on the edge of a mesa,

at the shore of a lake or bay, bring the important features into the middle of the finder. No picture should be taken that does not contain some life, as only professionals can make a good picture of still life. Picket a rodman with a level rod or stadia board of known length on a station 50 or 100 feet away on line—or more particularly at the point it is intended to feature. This not only gives life to the view, but provides a medium by which distances in the view may be estimated. Have, if possible, one-third of your view composed of sky. Balance your picture. Guard against having the center view obstructed by a 6 foot tree 15 feet from the camera, while the feature you are trying to photograph is 100 feet away. Such a composition blurs the foreground, reduces the field of view, and in general spoils what might have been a successful photo.

Hold or set the camera level. If it is necessary to obtain some feature that is below or above the outline as shown in the finder, manipulate the shifting front of the camera. Never tip the camera up or down, for to do so will produce distorted photos on account of the vanishing point lying outside of the horizontal plane.

Distance.—Ascertain the distance from the camera to the object to be photographed. Do this with reasonable care as too many poor negatives result from carelessness in estimating distances. Set the indicator at the proper point on the scale of distance. The nearer the subject is to the camera, the more care should be exercised in ascertaining the distance. For universal focus use stop U. S. 16, 32 or 64 and set focusing indicator at 25 to 30 feet.

Aperture and Time.—The aperture (stop) and time of exposure are the governing points in making an exposure.

For a given condition a number of different combinations of aperture and time will give satisfactory results. The larger the aperture the shorter the time. The smaller the aperature the better the detail of the picture becomes. In general it is desirable to use a fairly small aperture to get detail and as long a time as conditions permit.

The correct combination of aperture and time is affected by the use of a tripod, movement of objects, speed of plate or films used, altitude, latitude, season of the year, intensity of light and composition of the picture. This sounds complicated and is for the best results but fortunately considerable variation from the best timing will still produce a fairly good negative for all practical purposes.

Effect of Use of Tripod.—It is advisable to use a tripod for all engineering photography as it prevents blurring by movements of the camera during exposures and makes it possible to use a small aperture, with the necessary time of exposure, to get good detail. If the camera is held in the hands the time of exposure should be 1/25 of a second or less and the aperture will have to be made large enough to allow this speed.

Effect of Motion of Objects.—As a rule moving objects need not be photographed but if necessary the following speeds of exposure will stop motion.

$\frac{1}{25}$ of a second will stop wind in foliage.

$\frac{1}{50}$ of a second will stop pedestrians and slow moving rigs.

$\frac{1}{300}$ of a second distant trains.

$\frac{1}{500}$ to $\frac{1}{1000}$ of a second near trains, automobiles, etc.

The aperture must be regulated to allow these speeds.

That is, time governs aperture where motion is encountered. Under most conditions, however, where a tripod is used aperture governs time and a small aperture is desirable in order to obtain detail. For most landscape engineering survey work a U. S. stop 16, 32, or 64 is used and the time is varied to correspond with the stop selected.

Bright sun use stop U. S. 64 or U. S. 32.

Fair light use stop U. S. 32 or U. S. 16.

Moderate light use stop U. S. 16 or U. S. 8.

An aperture of U. S. 8 will give moderately good detail.

Speed of Plate or Film.—Different makes have different speeds but there is no great variation in the speed of the ordinary roll films or speed pack films and the following exposure chart is based on the commercial film in ordinary use.

Effect of Altitude.—Altitude has a marked effect on time of exposure. Exposure charts are worked out for sea level.

Wilson topographic surveying quotes Mr. E. Deville as stating that altitude has practically no effect on timing when the sun is near the zenith in the middle of the day but that as the sun approaches the horizon the effect becomes evident. He gives the following relative time of exposure at sea level and 10,000 feet altitude.

Altitude of Sun	Relative Time of Exposure	
	At 10,000 ft. Altitude	At Sea Level
90°	1 second	1 second
40°	1 "	1¼ "
25°	1 "	2 "
15°	1 "	3½ "

The rule generally used for ordinary engineering photography is to cut the time of exposure in half when you are working at an elevation of 5000 to 10,000 feet.

Effect of Latitude.—Exposures at the equator require the shortest timing.

As the latitude increased, the time of exposure increases.

For example conditions requiring $\frac{1}{25}$ of a second at the equator requires ¾ of a second in Alaska.

Effect of Season of the Year.—The summer months require less exposure than the winter months.

For example conditions requiring an exposure of 1/10 of a second in summer will require 1/5 of a second in winter, except that it must be remembered that snow on the ground changes the classification of "phase" discussed below.

The chart on page 429 is prepared for sea level at average conditions of latitude and season in the United States and the effect of latitude and season can be disregarded for all practical purposes except for extreme cases as they have a relatively small effect for this territory as compared to light intensity and phase of the picture.

The extreme variation from the chart will be approximately as follows; for winter months along the Canadian boundary, double the time of exposure given in the chart. For southern Florida in midsummer use 1/2 the time given in the chart.

When it is borne in mind that this variation in relative exposure does not ruin a negative it can be seen that unless these extreme conditions of combined location and season prevail that the chart time without correction should give reasonably good results. Altitude should however be considered.

EFFECT OF LIGHT AND PHASE

Light Values.—Judgment and experience are essential if good, average negatives are to be secured. However, the following discussion of light values of different lights and phases of views may be of use. There are five distinct conditions of light that are generally taken into consideration when calculating for an exposure.

(*A*) *Bright Sunlight.*—When the sun is shining brightly in a cloudless sky.

(*B*) *Light Clouds.*—When a thin film of white clouds partially obscures the sun, but fairly well defined shadows are discernible.

(*C*) *Diffused Light.*—An even light but no shadows.

(*D*) *Dull.*—Sky covered with dull clouds with no sunlight penetrating.

(*E*) *Very Dull.*—Sky overcast with very dark clouds. Gloomy.

Phases of Views.—For the purpose of classifying views or subjects in a view—the five following phases are given:

1. *Landscapes.*—This view contains distant landscapes, seascapes, snowclad hills, or broad expanses of river scenery. Such views reflect a large percentage of actinic light, and should be short timed or stopped down accordingly.

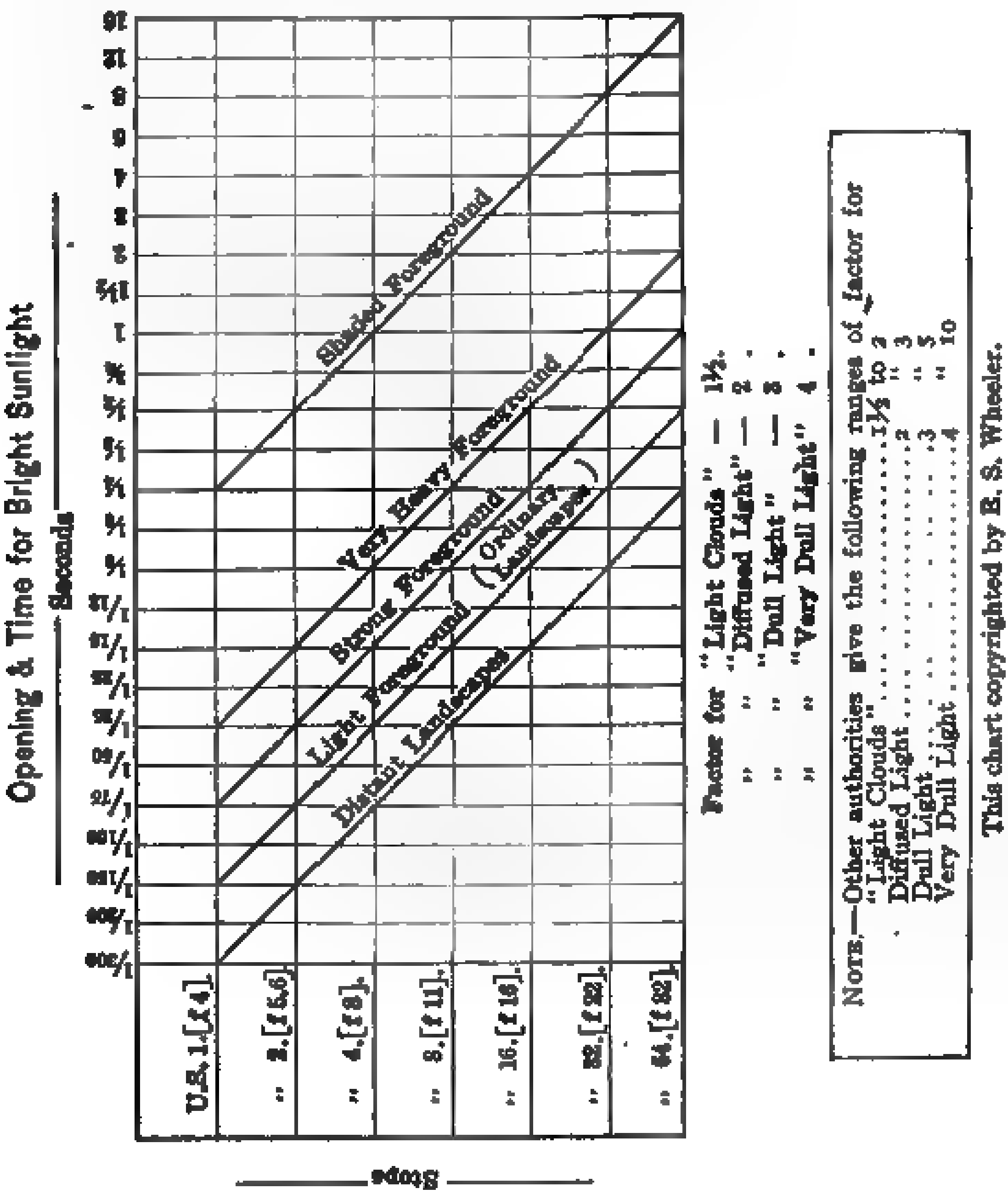
2. *Light Foreground.*—This view contains open fields and woods, flocks of live stock, buildings, and small expanses of water.

3. *Strong Foreground.*—This view contains a large percentage of foliage, buildings close enough to make strong and distinct outlines, fences, figures, animals, well defined roadways, rock cliffs, or well defined hill slopes not over 400 feet from the camera, urban scenes where the sky line is serrated with buildings, or full views of concrete structures.

4. *Very Heavy Foreground.*—This view contains close-ups of the following: landscapes having dark green foliage and shadows,

bridges and other structures with heavy shadows, and rock cliffs which are generally located in canyons where considerable direct light is shut out.

5. *Shaded Foreground.*—Under this caption comes, ravines, wooded hillsides, standing timber, under trees, and small dark box canyons where sun light is shut out by shadows.



Caution.—Great care must be exercised in making exposures for views under conditions for No. 5. Give plenty of time, and should doubt exist double the time taken from the chart and make another exposure.

Bearing in mind the five conditions of light "A" to "E," and

the five Phases of Views 1 to 5, enter the chart with the view as an argument. Along this line a number of combinations for time and stop may be had which will give satisfactory negatives. If detail is required, select a small stop, and from this get the time for Bright Sunlight "A." Should light conditions be other than "A" multiply the time obtained by the proper factor given below the chart.

For Example.—Condition of light: Diffused "C." *Phase of View:* Strong Foreground No. 3. Suppose you desire to use stop U. S. 8, the time for bright sunlight is given as 1/8 second. Multiply this time by 2 the factor for diffused light getting 1/4 second as the exposure required.

NOTE.—There are a number of meters now published which go into detail as to time, aperture, conditions of light and phases of view all of which give excellent results. These may be purchased from most any photo supply depot.

Exposure Record.—In order that the photographer may have something upon which to check up his failures, identify each view in connection with the project in hand, and properly reference them in the files, an exposure record should be used and each exposure carefully recorded. This record may take any number of forms, but from experience the following is suggested, which has been filled out to show how it is intended the columns should be used.

ROLL NO. 36. Exposure Made by Bill Jones ——— Sept.———

No. of Film	Job	Date	Hour	Light	Stop "f"	Time	Subject. Descriptive Notes
1	Rabbit Ears	5/8	9.00	A	16	1/10	Sta. 1007+40. Looking Az. 170 deg. along tang. Rodman on Sta. 1006.
2	Rabbit Ears	5/8	10.00	B	11	1/4	Old timber br. at Sta. 1026. Camera 60′ to right of 1019–50 looking Az. 130 deg. (out of focus).
3	Rabbit Ears	5/8	10.30	B	22	1/5	Sta. 1025 looking Az. 90 deg., showing proposed Xing of river. Solid rock in extreme left of view.
4	Rabbit Ears	5/8	4.00	A	11	1/10	Sta. 1091 looking Az. 270 deg., showing Amazon Pass, Hopland and Big River Valley.
5	Tyeras Canyon	5/9	10.00	C	8	1 sec.	Sta. 1107–45 looking Az. 210 deg. Dense timber along tangent.
6	Tyeras Canyon	5/9	3.00	D	22	1 1/2	Sta. 1136 looking Az. 226 deg. along tangent showing houses on right-of-way. Close up view. Rodman on Sta. 1137.

DON'TS

Don't expect good results from snapshots taken before 9.00 A. M. or after 5.00 P. M. even with sun shining brightly.

Don't try to make snapshots under trees or in a shadow. Make a time exposure resting the camera on a firm base, or better still, use a tripod. Get the proper time from the chart.

Don't hold the camera in your hand when making exposures over 1/25 of a second.

Don't attempt to make snapshots indoors.

Never face the camera at the sun unless necessary and then be sure to shade your lens from direct rays of the sun.

Always use small stops if detail is desired.

Don't give time exposures to distant landscapes. The farther away the subject the less time is required.

Buy only fresh films which will exactly fit your camera, and observe the date on same beyond which no guarantee of value is given.

Always turn the key bringing a new unexposed film into correct position after having made an exposure.

After having exposed a roll take it from the camera, and before putting in a new roll, examine the lens, try shutter, and blow out any particles of dust that might have worked into the bellows.

If after having made an exposure, the least doubt arises as to whether it was an overexposure, underexposure or double exposure, calculate for a stop and time, and proceed to make an exposure that will be satisfactory. This advise is of particular value to engineers, as it is not infrequent that the picture most needed is the one failure on the roll. The second exposure costs but ten cents. To secure it after the camp or work has been abandoned may cost a hundred dollars.

Developing.—Fairly good prints may be secured from average negatives, but the best prints are obtained from good negatives. To obtain good negatives the exposure must be reasonably correct, and development must be done with fresh and pure chemicals in quantities called for in the respective formulæ recommended by the makers of the plates or films used.

The simplest, most convenient, and most certain method of development that has been worked out for films, is what is generally known as tank development.

The equipment necessary to properly handle films of the size suggested in the beginning of this article is as follows:

1 E. C. Eastman tank No. 5E7 complete.
1 5 × 7 Gutta-percha tray.
1 32 oz. Measuring glass.
1 Stirring rod.
1 Thermometer.
1 or more pairs of film clips.
1 Dripping pan enameled, about 9″ × 12″.

The chemicals required for one roll of films are:

1 Tank developing powder for 5 × 7 tank.
4 oz. of hypo with acidifier.
Plenty of clear pure water having a temperature of 65° F.

As no dark room is required the development may be carried on at any time, and the process is as follows:

Dissolve the developing powder as per directions, using the developing tank, testing the same with the thermometer so that the solution when ready shall have temperature of 65°F. Set this aside.

Thoroughly rinse the measuring glass, and in 16 fluid ounces of water, dissolve the 4 ounces of hypo and acidifier. Pour this solution, know as fixer, into the 5 X 7 tray. Thoroughly rinse the measuring and glass stirring rod.

Prepare the films as directed in instructions accompanying the developing tank outfit, and wind it onto the opaque curtain.

This operation takes place in the light proof box.

Remove the spool containing the curtain and film, and place it in the tank containing developing solution, firmly fastening the top on the tank. Turn the tank end for end two or three times, holding it vertically for five or ten seconds each time, so as to expel all air from between the folds of the curtain, and insure complete contact between the developing solution and the film. At the moment of immersion, record the time, and permit development to go on for the specified time given for the temperature of the solution. If using Eastman Tank Developing Powder, and solution is 65°F., the time of development should be 20 minutes. Invert the tank every 5 or 7 minutes so that even development may be obtained.

Development having been completed, fill the dripping pan with fresh water, take the spool from the tank, and working rapidly, unroll the apron or curtain until the end of the film is visible. Firmly clamp a film clip, to this end of the film. Now lift the end of the film by this clip, unrolling it from the curtain until the other end of the film is free, and clamp another clip on this end. Rinse the film in the dripping pan of fresh water, running it through three or four times. Change to fixing bath, and run film through rapidly three or four times, making sure that the entire surface of the film is flooded with the solution, thus insuring that development is completely arrested.

Continue washing in the fixer until the film is clear. This will take from 7 to 10 minutes. Rinse in clear, cool, running water for one-half hour, or in 20 changes of water allowing the film to remain three to five minutes in each change After rinsing, suspend the film from a wire or hook, so that the same will hang free and permit it to dry. Do not touch the surface until perfectly dry. If the film has a tendency to curl during drying, leave it alone. The weight of the clip at the lower end will be sufficient to correct this.

When perfectly dry, trim the ends so as to leave as much unexposed film as there is between the exposures. Before cutting the film, place it on a table, back up, and under vertical views, or to the left of horizontal views, inscribe the information contained in the 8th column of the exposure record, together with the index

or filing number, using india ink. Place the index or filing number in a convenient space usually the upper left hand corner.

Cut the film, taking particular care that in so doing the legend and the view to which it applies, are together. Do not use scissors to cut the film, as this unless cleverly done, is apt to produce an irregular edge which is difficult to fit into the mask. Use straight edge and sharp pointed knife, or better still a trimmer, the latter costing about $1.75.

All operations to this point having been correctly performed, films will be uniform, have a neat and workmanlike appearance, and bear complete information as to date, subject, station from where taken, and index number. The film so labeled will be special, specific, and sufficient; special because it applies to a certain project, specific because it pertains to a particular point of feature of the project, and sufficient because it gives complete information.

CAUSES OF FAILURES

Not Sharp.	1. Objects moving or moving too fast.
	2. Out of focus.
	3. Camera being moved during exposure.
Under Time.	1. Use of too small stop.
	2. Light too weak.
	3. Exposures too short.
No Exposure.	1. Failure to set shutter.
	2. Failure to release shutter.
	3. Something in front of lens.
Double Exposure.	1. Failing to wind up film after making exposure.
Fogged.	1. Camera leaks light.
	2. Carelessness in loading or unloading.
	3. Taking pictures against sun.
Over Timed.	1. Stop too large.
	2. Too much time given.

Printing.—Equipment additional to that required for film developing:

1 Printing frame 5 × 7.
1 Gutta-percha tray 5 × 7.
1 Orange light.
1 Dish pan from camp kitchen.
Developing powders. (One tube of M-Q develops 18 prints of the size herein mentioned.)
4 oz. Hypo with acidifier.
4 oz. Bottle potassium bromide, 10% solution.
Quantity of 5 × 7 developing out paper, Azo preferred.

Procedure.—Prepare the developer by dissolving the contents of the tube as per direction thereon, and pour the solution into one tray, not the one used for fixing bath. In order that no doubt

CAMP EQUIPMENT

We would not have the temerity to recommend camp equipment any more than we would dare advise a woman on cooking utensils. It is a delicate subject on which most campers have their own pet notions. The following lists are more in the nature of reminders than anything else and are based on outfits in ordinary use on mountain road surveys in the west where equipment can be moved by wagon.

Outfit for an 8 or 10 Man Party on Location Surveys

Table Ware

White enamelware dishes unless otherwise noted.

	Item	Approx. Value
12	Cups, 3½" diameter	$2.00
12	Saucers, 6" "	1.80
3	Salt shakers (large) aluminum	0.60
1	" shaker (small) "	0.10
12	Table forks (retinned)	1.50
24	Tea spoons "	0.60
2	Meat platters, 16"	1.00
3	Pepper shakers (small) aluminum	0.60
1	" shaker (large) "	0.60
12	Plates, 9"	2.50
12	Table knives (retinned)	1.80
12	" spoons "	0.50
2	Water pitchers	1.50
2	Syrup "	1.50
12	Soup bowls, 5"	2.50
12	Sauce dishes, 5"	1.80
2	Sugar bowls, 6"	1.50
	Total value tableware	$22.40
	Say	$25.00

Cooking Utensils

	Item	Approximate Value
1	Butcher knife 10"	$1.00
2	" knives 8"	1.00
1	" knife 18" (steel)	1.00
1	Bread board	0.50
2	Basting spoons, 14" (retinned)	0.20
2	Berlin kettles, 10 quart (aluminum)	3.00
3	" " 6 " "	4.00
1	" " 5 " "	1.00
1	" " 4 " "	1.00
3	Bowls, 10" diameter earthenware	1.50
4	Buckets, 10 quart galvanized iron	1.50
1	Coffee boiler, 1½ gallon, gray enamel	0.70
1	" " 3 quart (aluminum)	10.00
2	Carving forks, wire (3 prong)	0.30
1	Cake turner (retinned, perforated)	0.10
3	Can openers	0.50
1	Collander, 9" (aluminum)	1.80
1	Dishpan, 17 quart (retinned)	0.75
1	" , 14 " "	0.60
3	Dippers, 1 pint "	0.50
1	Drip pan, 9"×11" "	0.25
1	" " 10"×12" "	0.25
1	" " 11"×16" "	0.25
12	Dish towels	2.00
1	Egg beater (family size)	0.15
2	Frying pans, 13" diameter steel	0.65

1	Frying pan 11½" diameter steel	0.25
1	Flour sieve (tin) 2 quart	0.20
2	Funnels (large)	0.40
2	" (small)	0.10
1	Grater	0.10
1	Jar for bread yeast, 3 gallon	0.75
1	Iron griddle, 20" × 12" cast iron	2.50
1	Meat saw	1.80
1	" chopper	0.50
1	" grinder	1.50
1	" cleaver, 8"	1.50
1	Milk pan, 6 quart (retinned)	0.50
3	Paring knives	0.40
12	Pie tins	2.25
1	Quart cup (retinned)	0.30
1	Rolling pin, 2⅝" × 10¾"	0.15
1	Stove pot	2.10
1	Skimmer (aluminum)	0.25
2	Soup ladles, 3" diameter	0.40
3	Serving pans, 12" diameter white enamel	1.75
4	" " 7" " " "	1.75
1	Tea pot, 1 gallon white enamel	0.60
1	Cook stove, 6 hole range, 18" × 18" × 12" oven, top 26" × 31" (30" high), weight approx. 250 lb.	25.00
	Total cooking utensils	$77.75
	Say	$80.00

Hardware

	Item	Approx. Value
4	Axes, 3½ lb.	$6.00
4	" 1½ lb. with sheath (hand)	5.00
6	Axe handles	2.00
2	Brush hooks or machetes	3.00
1	Cold chisel, small, 6"	0.10
1	Carborundum stone	1.20
1	Claw hammer, standard, 16 oz	0.80
4	Camp heaters with 5 joints nestible pipe (Sibley)	16.00
2	Files, mill bastard, 8"	0.50
1	Hasp	0.50
5	Oil lanterns 1¼"–1½" "wick Stalit"	5.00
3	Gasoline lanterns, "Quicklite"	17.00
2	Picks, railroad	2.50
2	Pick handles	1.60
1	Pliers, 7" lineman's	1.10
5	Piece nestible stove pipe for cooking stove	1.05
1	Screw driver, 18"	0.40
3	Sheath blocks C. I., ½" or ¾" rope	3.00
2	Shovels, sharp pointed, long handles	2.50
1	Saw, 4', one man in case	3.20
2	Sledges, 8 lb.	2.50
6	" handles	2.40
1	Saw, 26", 7 point, No. 7 Diston	1.80
4	Stove pipe protectors, asbestos	9.00
1	Tool grinder, No. 6 American	—
6	Boxes tacks, carpet, 8 oz.	0.50
	Nails, 8d and 20d	1.00
3	Balls twine	0.50
2	Tubs, 24" diameter galvanized iron	2.50
1	Whetstone	0.10
1	Washboard brass, 10½" × 11½"	0.60
4	Washbasins, enameled ware	1.00
100'	Wire baling	0.25
1	Wedge, splitting, No. 5 Truckee	1.10
1	Wrench, monkey, 8"	1.00
		$96.70
	Say	$100.00

Tents, Tables and Miscellaneous

Item	Approx. Value
2 Tents, 14′ × 16′	$180.00
3 " 10′ × 12′	110.00
1 Tent, 7′ × 9′	20.00
1 Kitchen table (see Figure 87, page 442)	15.00
1 Canvas mess table (see Figure 88, page 443)	25.00
3 Equipment chests (see Figure 86, page 440)	40.00
1 Mess box with padlock	5.00
1 Lantern box (see page 440)	5.00
2 Lunch baskets	3.80
6 Canvas chairs	6.00
4 " saddle bags	16.00
4 " note book shoulder bags	6.00
2 " water bags, 2½ gal	2.50
3 Canteens, 2 qt. with webbing and strap	5.00
100′ ¼″ rope	1.00
48 Clothes pins	0.20
1 Alarm clock	2.50
2 Scrub brushes, 1½″ × 4″	0.25
125′ ½″ rope	4.00
5 Yards oil cloth, white	1.40
2 Brooms	1.60
1 Spring balance, 50 lb.	0.40
1 Sailmaker's palm with needles, twine and wax	1.65
1 Shoemaker's outfit containing semi-steel, stand, 2 lasts and pegging awl	2.00
12 Hand towels	2.50
1 Medicine chest with remedies	30.00
	$486.80
Say	$500.00

Depreciation on Camp Equipment

Table ware	$ 25.00
Hardware	100.00
Cooking utensils	80.00
Tents, etc.	495.00
Total	$700.00

Allowing for ordinary wear, accident, loss, etc., this equipment is probably good for three years. Allowing 50 miles of survey per season for each party which is a fair average, the equipment is good for 150 miles of survey or at the rate of $4.50 per mile which is a reasonably close charge for the use of camp equipment on survey work of this character.

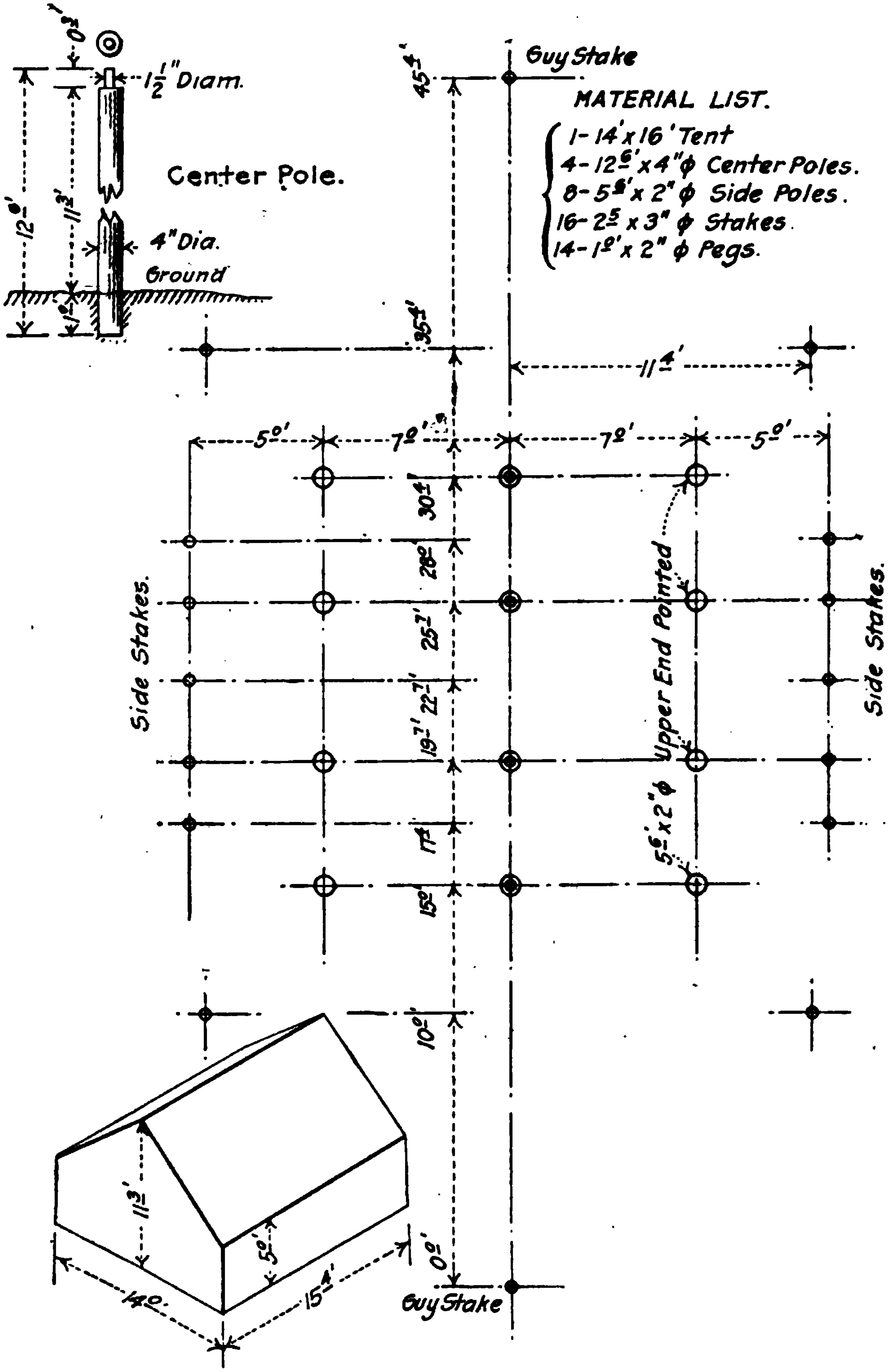


FIG. 85.—Layout diagram.

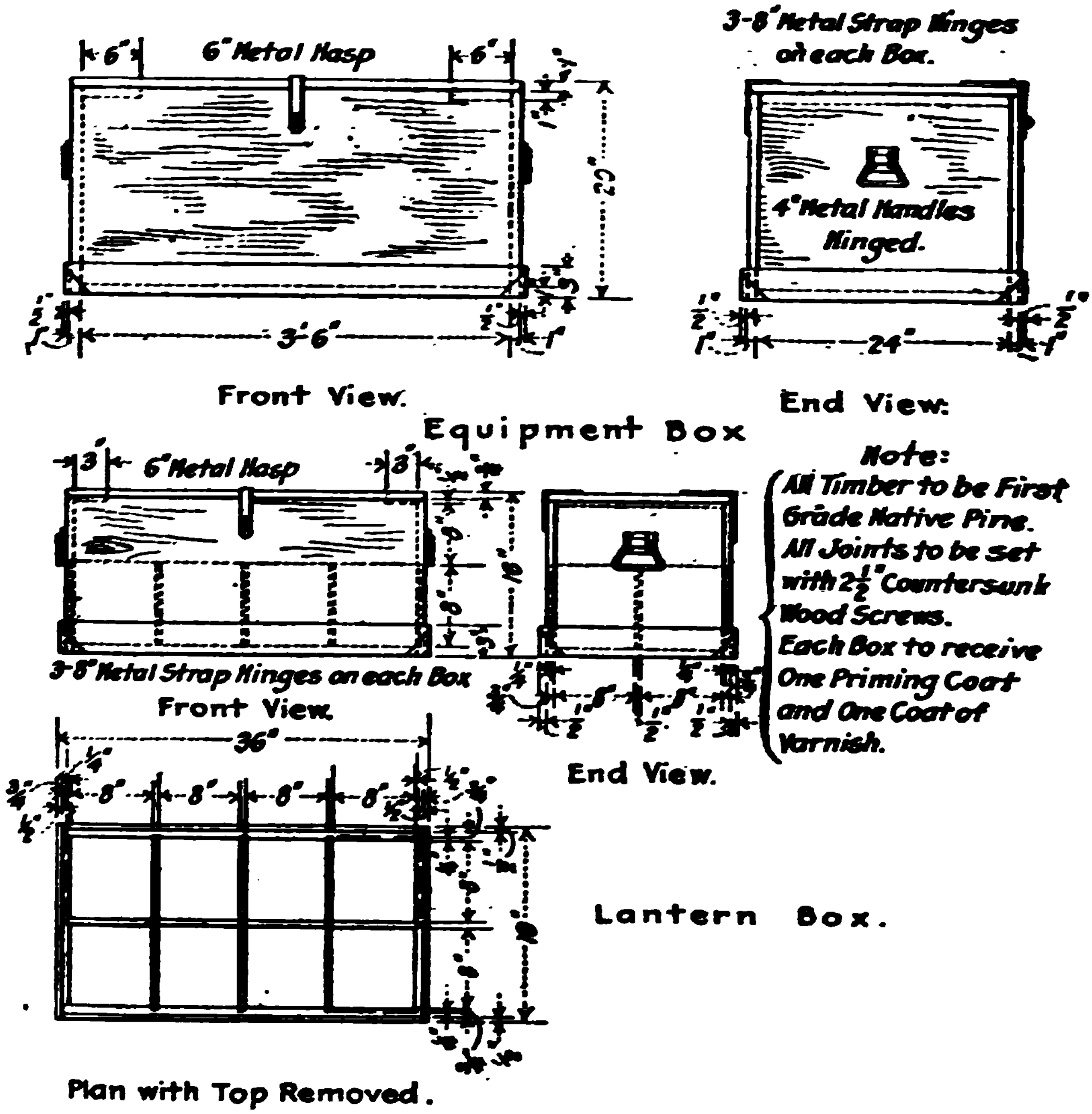
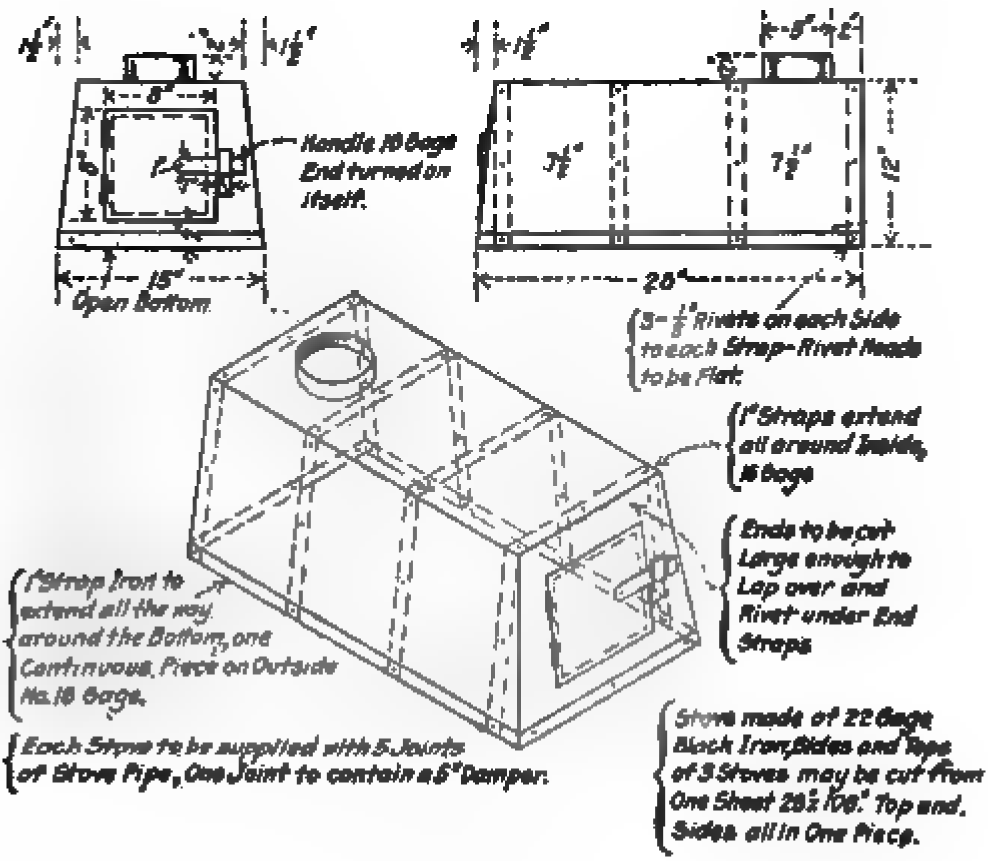

6" Metal Hasp
3-8" Metal Strap Hinges on each Box.
4" Metal Handles Hinged.
3'-6"
24"
Front View.
End View.
Equipment Box
6" Metal Hasp
3-8" Metal Strap Hinges on each Box
Front View.
End View.
Note:
All Timber to be First Grade Native Pine.
All Joints to be set with 2½" Countersunk Wood Screws.
Each Box to receive One Priming Coat and One Coat of Varnish.
36"
Lantern Box.
Plan with Top Removed.

FIG. 86.


15"
Open Bottom
Handle 16 Gage End turned on itself.
28"
12"
3-1/8" Rivets on each Side to each Strap-Rivet Heads to be Flat.
1" Straps extend all around Inside, 16 Gage
Ends to be cut Large enough to Lap over and Rivet under End Straps
1" Strap Iron to extend all the way around the Bottom, one Continuous Piece on Outside No. 16 Gage.
Each Stove to be supplied with 5 Joints of Stove Pipe, One Joint to contain a 5" Damper.
Stove made of 22 Gage Black Iron, Sides and Tops of 3 Stoves may be cut from One Sheet 28" x 106". Top and Sides all in One Piece.

Tent heater.

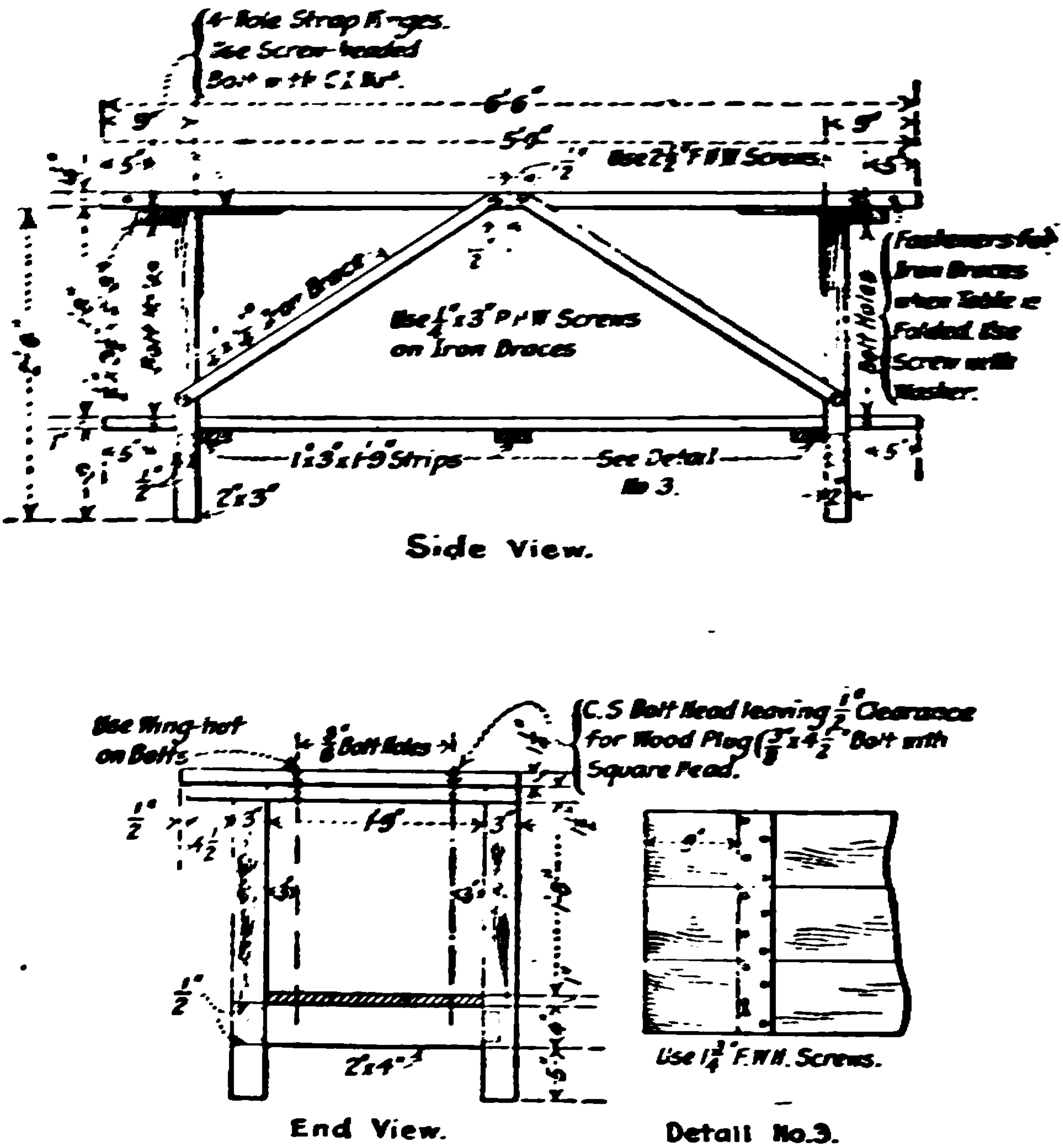


FIG. 87.—Folding kitchen camp table.

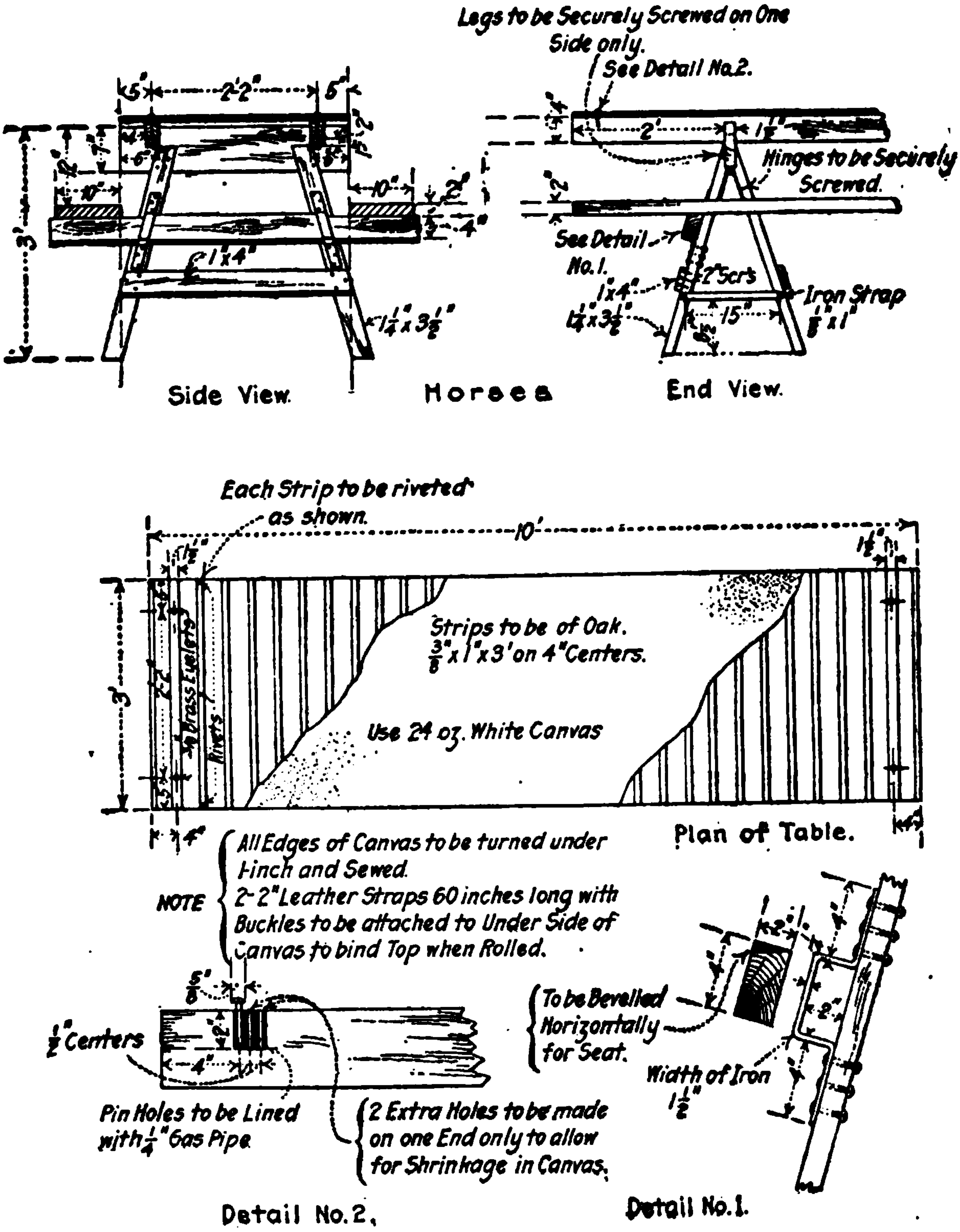


FIG. 88.—Portable mess tables.

Survey Party

Ration—(one man one day)

Article	Unit	Quantity
Fresh meat	pounds	0.70
Cured meat	"	0.30
Lard	"	0.14
Flour	"	0.70
Corn meal	"	0.05
Baking powder	"	0.02
Sugar	"	0.35
Coffee	"	0.05
Tea	"	0.01
Butter	"	0.14
Dried fruit	"	0.10
Rice, beans or hominy	"	0.10
Potatoes	"	1.00
Salt	"	0.04
Flav. extracts	ounces	0.03
Spices	"	0.05
Milk, condensed	cans	0.40
Canned fruits	"	0.18
Vegetables (fresh or canned)	pounds	0.50
Syrup	"	0.06
Pickles	"	0.03
Eggs	nos.	2½
Breakfast foods	pounds	0.08
*Miscellaneous cost		2½c.

* Miscellaneous includes, crackers, yeast, chile powder, soda, salad, oil, catsup, chocolate, lemons, soap, sapolio, candles, matches, oil and wood. An allowance of 2½c. per ration should easily supply these items.

NOTE.—Fresh milk may be substituted for condensed at a rate of 1 quart for one can.

Cost of Ration.—The cost of feeding one man per day including cook's salary based on 5000 man day rations in 1918 on Western Mountain Location Surveys averaged $1.30.

Preliminary Investigation Outfit

Where one man is traveling alone on foot and will be out of touch with habitation for a day or so at a time a simple outfit carried in a knapsack or pack basket will serve very satisfactorily.

1	Waterproof canvas sleeping bag	$15.00
1	Light belt axe	1.00
1	Small fry pan	0.25
1	Cup with long handle for heating water	0.25
	Knife, fork and spoon	0.50
	Matches in bottle or waterproof case	0.10
	Small emergency food supply	2.00
	Personal supplies	
	Canteen in arid regions	

This whole pack will not weigh over 30 lb. and can be easily carried.

NOTES ON PERSONAL HYGIENE AND CAMP MEDICINE

General Note.—Anyone responsible for a party of men in the field should make a careful study of this subject. Miscellaneous Publication No. 17 of the United States Health Service on the "Prevention of Disease and Care of the Sick" can be obtained by anyone free of charge and covers in a very thorough manner the points that we can only touch on in a book of this character. Much of the data following is quoted or briefed from this source supplemented by the author's personal experience. The material on First Aid is quoted verbatim from Bulletin No. 17 of the U. S. Public Health Service by courtesy of that department.

Personal Hygiene.—Camp life is at its best a dirty proposition and every care should be taken to retain as far as possible the ordinary regular and cleanly personal habits. Proper clothing should be worn, excess in eating or drinking should be avoided, the bowels should be kept regular, the body clean and the teeth and feet well cared for. Many a novice in camping goes without the ordinary personal toilet articles either because he thinks that under the circumstances they are not in good form or because he forgets them, but it should be remembered that for anyone accustomed to their use, the lack of a tooth brush often causes sore mouth or gums; the lack of toilet paper often causes piles and that a razor adds wonderfully to the enjoyment of the Sunday in camp.

Clothing.—In high altitudes heavy woolen underwear should be worn even if the midday temperature is high as the rapid cooling at night is injurious unless this precaution is taken. Mountain fever is often brought on by overheating and chilling caused by the rapid cooling at night. If the work involves wetting by fording cold streams or intense rain, woolen clothing is essential. Under these conditions if the air temperature is low the woolen clothes should be worn until dried at a fire and never removed while wet. If the air temperature is high particularly in the tropics wet clothing should be removed immediately and dried.

In the tropics silk or silk wool light underwear next to the skin adds to the comfort. Flannel about the abdomen must be worn at all times.

The army campaign hat of the heavy felt sombrero type is very comfortable for all ordinary work. The close fitting canvass fur lined caps for cold weather and the pith helmet for tropical conditions. The more intense the sun the heavier the head covering should be.

In intense light, colored glasses with side flaps fitting closely to the temples add greatly to the comfort and prevent eye troubles such as snow blindness, etc.

Where much walking is done heavy cotton socks are desirable in warm weather and heavy woolen socks in cold weather. Socks should be free from holes or lumpy darns and should be frequently changed.

Rubber boots should not be used.

Leather shoes with heavy extension soles are the most satisfactory even in snow or water. Four buckle arctics may be worn over them in snow. For intense cold German felt socks and felt boots are desirable.

For ordinary summer conditions kaki trousers and a light flannel shirt is a satisfactory outside rig. For cold weather a tight woven canvas trouser worn over a warm woolen trouser keeps the wind out and the heat in and a sheep lined or blanket lined leather or moleskin pea jacket makes a suitable body covering. In rain an oilskin slicker is better than a rubber coat.

In steep wooded side hill work in a rattlesnake county stiff canvas leggins, tight woven canvas trousers and leather gauntlet gloves are desirable.

Bedding.—The most satisfactory portable camp bed is the waterproof canvas sleeping bag lined with woolen blankets. In this connection it should be noted that if it is possible to do so avoid sleeping on wet ground.

Diet.—Stick to your normal diet but avoid overeating or drinking. In extremely hot weather avoid heavy meats. On a long tramp in hot weather do not drink water freely. More endurance results from controlling your thirst. Do not use alcoholic liquors except for medicinal purposes.

Be very careful of the drinking water; impure drinking water causes typhoid fever, dysentery and malarial complaints. Boiling is the surest method of treating doubtful water. Muddy water should be filtered.

A bath should be taken once a day but prolonged immersion particularly in cold water is injurious and lowers the vitality. Soaking the feet in cold water tends to toughen them.

Care of Mouth and Teeth.—Before going on a camping trip get a dentist to put your teeth in perfect condition. There is nothing more annoying

than a bad toothache under conditions where expert treatment is not available. If toothache develops accompanied by swelling locate the cavity and break into it allowing the gases to escape. If the toothache is a sharp shooting pain with no swelling it is probably an exposed nerve. Pack the cavity with cotton saturated with clove oil, laudanum or chloroform. If toothache develops without an apparent cavity the application of heat to the seat of the pain will often cause relief.

The teeth should be brushed at least twice a day using a good tooth powder or castile soap.

An unclean condition of the mouth renders a person more liable to attacks of influenza, bronchitis and pneumonia.

Care of the Feet.[1]—1. A good marching shoe should be large enough in all directions, but not too large. If the foot moves in the shoe it is liable to chafe and blister. A common defect in shoes is that they are too tight over the instep and too loose across the ball of the foot. If the leather forward of the instep is too slack, wrinkles will form. Folds of leather and rough inner seams should be avoided. The inner edge of the shoe should be almost straight, the sole thick and wide, projecting beyond the upper leather. The heel should be low and broad, and the toe of the shoe should be of such a length that there will be no pressure on the ends of the toes or toenails.

2. The toenails should be cut straight across, a little behind the end of the toe, and should not be rounded. Any tendency to ingrowing should receive treatment at once.

3. Corns and callosities are due to pressure and friction from unhygienic shoes. When between the toes they are soft; on other parts they are dry and hard. They often render men unfit for duty.

Treatment.—(*a*) Remove the cause by wearing hygienic shoes. Soak the feet well in hot water, thoroughly disinfecting them with bichloride (1 part bichloride of mercury to 2000 parts water) or other disinfectant and then pare the corn or callus down with a sharp knife without wounding the skin. The hands of the person and the knife should be sterilized before the operation is performed. Fragments of glass and sandpaper should not be used on corns. Persons should be cautioned about the care and treatment of corns as a slight wound of the foot may lead to lockjaw or blood poisoning. Soft corns should be treated by applying a dusting powder like aristol on cotton or gauze between the toes.

(*b*) Apply the following collodion paint with a camel's-hair brush, night and morning, for several days, then soak the feet in hot water, and the corn will come away painlessly:

Acid salicylic	1 dram
Extract cannabis indicæ	10 grains
Collodii	1 ounce
M. C. Corn paint.	

4. *Blisters.*—Save the skin; drain at the lowest point with a clean needle. Protect with adhesive plaster.

5. *Excessive and Foul Perspiration.*—Excessive perspiration often leads to foot soreness, blisters, fissures, and corns and may be offensive.

(*a*) Mild cases will be relieved by dusting into the shoe and onto the foot the following "foot powder."

Acid salicylic	3 parts
Pulverized amyli	10 parts
Talci	87 parts

This foot powder may be used with benefit before a march, especially in case of sore or tender feet.

(*b*) Severe cases will be relieved by soaking the feet, after a preliminary scrub with soap and water, in a solution of permanganate of potassium. The stain should be left on the feet. The solution should be gradually increased from 1 per cent. to 6 per cent. and the treatment continued nightly for three weeks. The foot powder should be used during the day.

(*c*) Another method of treatment is to sprinkle a few drops of formalin into the shoe each morning.

6. The feet should be well greased with tallow or neat's foot oil before a

[1] Quoted from the Landing Force and Small Arms Instructions of the U. S. Navy.

march; or the inside of the stockings should be covered with a stiff lather of common yellow soap well rubbed in, or the foot powder may be freely used.

7. Should the stockings cause pain, the pressure is sometimes relieved by shifting them to the other foot or by turning them inside out. Within two hours after reaching camp the feet should be wiped off with a wet cloth, clean stockings put on, and those which are removed washed for the following day, if possible.

8. Men unaccustomed to marching may toughen their feet by soaking them in strong, tepid, alum water (a teaspoonful to a pint.)

Fly and Mosquito Dopes.—During certain seasons field work is made very annoying in thickly wooded county by flies and mosquitoes and unless some relief is obtained a man taking notes gets nervous and makes mistakes.

Small flies such as punkies and mosquitoes will not bite if the face and hands are covered with oil of citronella or a mixture of ½ wood tar oil and ½ sweet oil. The citronella evaporates rapidly and has to be renewed at short intervals but it does not stain a notebook and has a rather pleasing odor.

The tar oil is more lasting and is more effective but is rather of a dirty looking mess although the odor is not unpleasant. It will stain a notebook or plain table sheet and can not well be used on the hands of a man doing this class of work.

Insect Bites and Stings.—Spider bites and bee stings can be relieved by moistened baking soda applied on the bite or Hartshorn and water half and half. Ice cold water will reduce the swelling after the pain has been relieved.

Vermin and Insect Pests.—Accidents will happen in the best regulated families and the author has often frantically hunted for a cure for these evils that are encountered in logging camps and picked up in all sorts of ways.

Fleas.—A house may be rid of fleas by sprinkling flaked naphthalene on the floors and leaving the rooms closed for a number of hours. Kerosene will kill them. Chloroform is useful in killing fleas on the body as it can be poured through the clothing directly on the spot where the flea is located.

Lice.—There are three kinds of lice, head lice, body lice and crab lice.

The following data on vermin is quoted from the Health Service Bulletin No. 17.

"Every effort should be made to free the body from lice and their eggs if one should be so unfortunate as to become infested with these insects. The head louse is destroyed by washing the hair with a mixture of equal parts of kerosene and vinegar, care being taken that it does not run down over the face or neck. The vinegar dissolves the sticky substance which binds the nits to the hair, and the kerosene kills the lice. Gasoline is as effective as kerosene, but it should not be used as its inflammability is much greater than kerosene. The danger of burning a patient in case either of these preparations is employed should be borne in mind, and the patient should be outdoors at the time of application and remain outside until the hair becomes dry. Several applications at intervals of two or three days are required, as the nits, or eggs, are hard to kill. These may sometimes be combed from the hair with a fine-toothed comb. The body louse lives in the clothing, so this should be boiled or baked. If this is impossible the clothing, and especially the seams, should be ironed with a hot iron. An efficient method is to soak the clothing in gasoline, or the vapor of gasoline may be forced through them. Another less expensive method is to put the clothes for half an hour in a soapy solution to which 2 per cent. of trichlorethylene has been added. A good application to the body is a solution made by mixing 1 part of gasoline with 3 parts of vaseline. This preparation is noninflammable under working conditions. An ointment made by mixing 5 parts of naphthalene with 95 parts vaseline is also useful for this purpose. Pubic lice, commonly known as "crabs," are destroyed by the application of white precipitate, or mercurial ointment.

"Lenz found that he could eradicate lice from prisoners at Pucheim (near Munchen) by means of finely powdered naphthalene. A handful of this material is put into the patient's clothing, introduced through the opening at the neck. He is made to sleep at night with all his clothes on. The body heat causes the naphthalene to evaporate, the vapor killing not only the lice but also most of the eggs. This treatment should be repeated every four days for a period of twelve days.

"In the British Army a powder composed of naphthalene (96 parts), creosote (2 parts), and iodoform (2 parts) is used. About two-thirds of 1 ounce is required for each man. Two tablespoonfuls of an ointment made

of crude mineral oil (9 parts), soft soap (5 parts), and water (1 part) is rubbed into the interior seams of the clothing. Articles of underclothing are treated by dipping and wringing them out in a solution of 1 per cent. each of naphthalene and sulphur in benzene or gasoline.

"**Itch Mite.**—The itch mite is a small parasite which burrows into the skin and produces a disease known as the itch or scabies. The irritation produced by the mite causes scratching, which results in excoriations, papules, and postules at places where the mite has entered.

"**Prevention.**—A person with the itch should be careful not to shake hands with other persons. He should use separate towels and sleep in a bed by himself. He should, as far as possible, keep away from other people, particularly children, as they are especially susceptible to the disease.

"**Treatment.**—The patient should take a hot bath, using plenty of soap, and an ointment composed of powdered sulphur (2 teaspoonfuls) and vaseline (8 tablespoonfuls) should then be well rubbed into the skin. The treatment is continued for three nights, and on the morning of the fourth day the patient takes a bath and puts on clean clothing. If there is burning of the skin, a little zinc ointment may be rubbed in. The underwear and bed clothing should be boiled and the outerclothing ironed or baked. The treatment should be repeated after an interval of three or four days if itching is still present. Another method of treatment is to rub the body with powdered sulphur every night for a week after taking a bath and also sprinkle it between the bed sheets at night, and on the underwear during the day. The sheets and underwear should be changed each day.

"**Ticks.**—Ticks are believed to feed upon blood alone. They attach themselves to the skin of man and animals and partly burrow into it. They hold on tenaciously. If carelessly pulled off, the head may be torn from the body and remain in the skin. The eggs of ticks are deposited upon the ground. The larvæ are six-legged creatures which catch hold of any animal within their reach. After becoming engorged with blood the larva drops off and changes to the third or nymph stage. The nymph, after obtaining more blood and shedding its skin, changes to the adult insect. The tick is instrumental in spreading Rocky Mountain spotted fever throughout some parts of the country. It should be removed from the skin by means of hartshorn, kerosene, turpentine, or carbolized vaseline, which prevent the head remaining in the skin. Persons traveling through woods or other places in a tick-infested country should stop and search their bodies every two or three hours and remove any ticks that may have attached themselves thereto.

"**Bedbugs.**—The presence of bedbugs in dwellings is indicative of want of care and cleanliness as to bed, bedclothes, etc., and means should be taken to exterminate them when they appear. A liberal application of kerosene oil to the places infested is probably the best means of killing them. There are preparations of gasoline or naphtha sold which leave no stain when sprayed on painted or papered walls. Badly infested rooms may be freed from bedbugs by fumigating with sulphur, using 2 pounds of sulphur to every thousand feet.

"**Roaches.**—Roaches are believed to be responsible for the conveyance of tuberculosis, diphtheria, typhoid fever, tonsillitis, and possibly some other disease. They spread these diseases by carrying the organisms on their feet and in their intestinal canals and disseminating them over food supplies, books, and other articles in daily use. They are especially abundant in the galleys of vessels and in damp kitchens. They appear at night after the lights have been turned off and overrun everything in the room. Roaches can be quickly, cheaply, and completely exterminated from ships and houses by the use of sodium fluorid. This should be spread with a rubber powder blower on the floors near the walls and on shelves in closets. The powder does not suffocate the insects, but sticks to their feet. They clean it off with their mouths, some of it being swallowed and causing the death of the insect. As sodium fluorid is poisonous to man in doses of a tablespoonful or more care should be taken not to spread it over articles that are to be eaten."

LIST OF MEDICAL AND SURGICAL SUPPLIES FOR MEDICINE CHESTS
MEDICAL SUPPLIES (U. S. Health Bulletin, No. 17).

For Vessels	For Homes and Factories	Item
1 pound	1 pound	Absorbent cotton.
1 pint	½ pint	Alcohol.
2 ounces	2 ounces	Argyrol, 10 per cent. solution.
½ pint	4 ounces	Aromatic spirit of ammonia.
100	100	Aspirin, 5-grain tablets.
1 yard	1 yard	Belladonna plaster (1 year).
4 ounces	4 ounces	Bicarbonate of soda (baking soda).
100	100	POISON. Bichloride of mercury. Antiseptic tablets of 7.3 grains each. One tablet to a pint of water makes solution 1 part of bichloride to 1000 of water.
100	100	Bismuth subnitrate, 5-grain tablets.
½ pound	4 ounces	Borax.
1 pound	½ pound	Boric acid (boracic acid) powdered.
100	100	Bromide of potash, 5-grain tablets.
100	100	Brown mixture lozenges.
100	100	Calomel and soda tablets, each 1/10 grain of calomel and 1/10 grain of bicarbonate of soda; amber-colored bottle (1 year).
		Calomel and soda tablets, each ½ grain of calomel and 1 grain of bicarbonate of soda; amber colored bottle (1 year).
100	100	POISON. Camphor and opium pills.
½ pint	4 ounces	Camphorated oil.
1 pint	½ pint	POISON. Carbolic acid, liquid, pure.
1 pint	½ pint	Castor oil.
100	100	Chlorate of potash, 5-grain tablets.
100	100	Compound cathartic pills, vegetable.
1 pint	1 pint	POISON. Compound solution of cresol.
100	100	Copaiba, 5-minim capsules.
1 ounce	½ ounce	POISON. Creosote, beechwood.
1 pint	½ pint	Dobell's solution.
1 ounce	1 ounce	Ear drops, formula: Carbolic acid, 1 fluid dram; glycerin, 7 fluiddrams; well mixed.
2 pounds	1 pound	Epsom salt.
½ pint	4 ounces	Essence Jamaica ginger.
4 ounces	2 ounces	Essence of peppermint.
1 pound	½ pound	Flaxseed meal (linseed meal).
1 pint	1 pint	POISON. Formalin (1 year).
1 pint	½ pint	Glycerin.
100	100	Iodide of potash, 5-grain tablets.
4 ounces	2 ounces	POISON. Laudanum (1 year).
1 pint	½ pint	POISON. Lead and opium wash. Shake well before using.
½ pound	4 ounces	Magnesia, calcined, heavy.
2 ounces	2 ounces	Menthol solution; Menthol, 3 grains liquid, petrolatum, 1 ounce.
½ pound	4 ounces	Mustard.
1 ounce	½ ounce	POISON. Oil cloves.
1 pint	1 pint	Olive oil (sweet oil).
½ pint	½ pint	POISON. Oil of wintergreen (methyl salicylate).
½ pint	4 ounces	POISON. Paregoric.
100	100	Permanganate of potash, 5-grain tablets.
1 pint	1 pint	Peroxide of hydrogen solution (1 year).
1 pint	½ pint	POISON. Picric acid, ½ per cent. solution.
100	100	Quinine sulphate, 5-grain tablets.
100	100	Salicylate of soda, 5-grain tablets.

MEDICAL SUPPLIES—(*Continued*)

For Vessels	For Homes and Factories	Item
100	100	Salol, 5-grain tablets.
½ pint	4 ounces	Syrup of ipecac.
1 quart	1 pint	Soap liniment.
100	100	POISON. Strychnine sulphate, $\frac{1}{60}$-grain tablets.
100	100	POISON. Sun cholera mixture, 15-minim tablets.
½ pint	4 ounces	Sweet spirit of niter, dark colored bottle (1 year).
½ pound	4 ounces	Tannic acid.
1 pint	½ pint	Tincture of green soap.
½ pint	4 ounces	POISON. Tincture of iodine (1 year).
½ pint	4 ounces	Tincture of iron.
½ pint	4 ounces	Tincture of myrrh.
1 pint	½ pint	Turpentine.
1 pound	½ pound	Unguentine (for burns, scalds, etc.).
1 pound	1 pound	Vaseline.

These medicines will remain serviceable until used if kept in glass-stoppered bottles, with the exception of those marked "1 year" which should be renewed after that interval. The containers of all articles marked "1 year" should be plainly marked with the date on which such articles are received.

For bulky articles not over a pint of each need be kept in the medicine chest.

Special bottles with a rough surface must be used for poisonous medicines. These bottles must be plainly marked POISON.

Gauze and bandages should be in paraffin-paper packages, sealed after sterilization.

Catheters and other rubber goods should be in sealed paraffin packages or envelopes, slightly dusted with sterile talcum on the inside of the package.

Scissors and instruments, if not in cases, may be coated with paraffin, which will come off when dipped in hot water.

Articles marked "1 year" should be discarded after that interval and new ones obtained. The containers of all articles marked "1 year" should be plainly marked with the date on which such articles are received.

SURGICAL SUPPLIES, ETC.

For Vessels	For Homes and Factories	Item
2	1	Adhesive plaster, 10-yard reel, 1 inch wide.
2 dozen	1 dozen	Applicators, small, wooden.
1	1	Atomizers, DeVilbiss.
1 dozen	1 dozen	Bandages, 2 inch by 3 yard (½ dozen gauze and ½ dozen muslin).
1 dozen	1 dozen	Bandages, 2 inch by 5 yard, (½ dozen gauze and ½ dozen muslin).
4	2	Bandages, plaster of Paris, 3-inch. Each contained in an air and moisture proof container.
1 dozen	1 dozen	Bandages (4 inch by 5 yard muslin).
6	6	Bandages, triangular (Esmarch's bandage), with figures printed on them showing the various ways they can be used.
1	1	Bistoury.
6	3	Camel's-hair brushes.
1	1	Catheter, rubber, No. 20 F (1 year).
1	1	Corkscrew.
1	1	Forceps, artery (hemostatic forceps). This can be used to grasp a bleeding vessel until it can be tied, or until the doctor arrives. A catch holds the grip of the forceps. Sterilize by boiling.
1	1	Forceps, dressing or dissecting. Will be found convenient in cleaning up a wound and applying dressing; also in removing splinters, etc. Sterilize by boiling.
1	1	Fountain syringe, 2 quart (1 year).
6	6	Urethral syringes, glass.
10 yards	5 yards	Gauze, picric acid. Good dressing for wounds and scalds.
10 yards	5 yards	Gauze, plain, sterile.
1	1	Hot water bottle, rubber, 2 quart (1 year). Metal bottle preferred.
6	6	Medicine droppers.
1	1	Medicine glass.
2	2	Nail brushes.
2 dozen	2 dozen	Safety pins, large.
1	1	Scissors, dressing, surgeon's, for cutting gauze and bandages. Sterilize by boiling.
1	1	Shears, for cutting cotton and muslin, etc.
6	3	Splints, wooden. Straight and angular splints made of this board, as described in chapter on "Fractures."
1	1	Spool of silk ligature, medium size.
2	2	Surgical needles, in glass-stoppered bottles.
2	2	Thermometer, clinical, Fahrenheit.
1	1	Tooth forceps, incisor.
1	1	Tooth forceps, molar.
4 pieces	2 pieces	Wire gauze, made of heavy mesh malleable wire. When well padded can be wrapped around a fracture for temporary dressing.
4 sheets	2 sheets	Yucca palm (a thin fiber board). Can be wrapped around a fracture for temporary dressing.

LIST OF REMEDIES MENTIONED AND THEIR USES

(U. S. Health Bulletin No. 17)

Doses.—Unless otherwise stated, the doses mentioned in this book are intended for adults. To determine the dose for children, add 12 to the age of the child and divide the age of the child by this sum. This fraction will represent the size of dose compared with that for an adult. For example, a child 6 years old will require $\frac{6}{6+12} = \frac{6}{18}$ or one-third of the adult dose.

Caution.—Preparations containing opium, such as laudanum, paregoric, camphor and opium pills, Sun Cholera Mixture tablets, etc., should not be used except where absolutely necessary, as their continued use is liable to produce the drug habit.

Alcohol.—Externally is useful as a mild antiseptic wash for wounds. As a liniment, pure or diluted with from 1 to 3 parts of water, is cooling and stimulating.

Argyrol.—Useful, in 10 to 20 per cent. solutions, as drops for sore eyes, also as injection for gonorrhea.

Aromatic Spirit of Ammonia.—Useful in hysteria, faintness, headache, flatulent colic, nervous debility, and as a stimulant in shock. Dose: ½ to 1 teaspoonful in water every half hour until three doses are taken.

Aspirin (5-grain tablets).—Useful in rheumatism, neuralgia, and headache. Dose: 1 to 2 tablets with hot water or tea every three hours.

Belladonna Plaster.—Useful in coughs, colds, rheumatism in joints and arms, lumbago, and pains in small of back. Should be worn only long enough to have the desired effect. If the throat becomes dry or the pupils dilated, indicating belladonna poisoning, the plaster should be removed.

Bicarbonate of Soda (baking soda).—Internally useful in sour stomach and heartburn. Dose: ½ to 1 teaspoonful in half tumbler of water. Repeat in half an hour if necessary.

Bichloride of Mercury Tablets (poison, 7.3 grains each).—One tablet dissolved in from 2 to 5 pints of water makes a powerful and efficient solution for washing and dressing wounds, sores, and boils. Do not use internally.

Bismuth Subnitrate (5-grain tablets).—Useful in dysentery, diarrhea, and heartburn. Dose: 2 to 4 tablets every three hours. (Crush before taking.)

Borax.—Useful in sore mouth. One tablespoonful dissolved in a pint of water and used as a mouth wash several times a day.

Boric Acid (boracic acid).—One-half teaspoonful may be dissolved in a glass of water and used as a lotion for the eye or ears.

Bromide of Potash (5-grain tablets).—Useful in neurasthenia, convulsions, and delirium tremens. Dose: 3 to 5 tablets, dissolved in water, three times a day.

Brown-mixture Lozenges.—Useful in bronchitis, coughs, and colds. Dose: 1 lozenge allowed to dissolve slowly in mouth, to be repeated as required.

Camphor and Opium Pills (poison).—Useful in relieving pain in diarrhea and dysentery. Dose: 1 pill every three hours until 4 are taken.

Calomel (1/10-grain tablets).—Useful in constipation and dysentery. Dose for adults and children: Take 2 tablets every 15 minutes until 20 tablets are taken. When from 4 to 6 hours have elapsed a Seidlitz powder or a dose of Rochelle or Epsom salt should be taken. The dose of the Seidlitz powder or salt should be proportionate to the age of the patient.

Camphorated Oil (for external use only).—In sprains, bruises, neuralgia, rheumatism, and pains and swellings of the breasts or joints it should be gently rubbed on the painful part. Applied on hot flannel to chest and neck for colds.

Carbolic Acid, Liquid (poison).—Useful as an antiseptic and disinfectant when mixed in the proportion of 1 part of acid to 100 parts of hot water. Useful without dilution to arrest the development of boils and carbuncles and as an application to ulcers and venereal sores. Should be applied cautiously. The surface should be merely touched with a small piece of cotton moistened with a drop of the acid, care being taken not to burn the surrounding skin. Do not use internally.

Castor Oil.—Useful in constipation. Dose: 1 to 2 tablespoonfuls.

Chlorate of Potash (5-grain tablets).—Useful in sore throat and sores in mouth. Directions: Dissolve 5 or 6 tablets in a wineglass of water and use as a gargle or mouth wash.

Compound Cathartic Pills, Vegetable.—Useful in constipation. Dose: 1 to 3 pills at night.

Compound Solution of Cresol.—Useful as antiseptic and disinfectant when mixed with water in from 1 to 3 per cent. solutions. Do not use internally.

Copaiba (5-minim capsules).—Useful in gonorrhea and inflammation of the bladder. Dose: 1 to 2 capsules three times a day.

Cream of Tartar.—In small doses (1 to 2 teaspoonfuls in sweetened water) acts as a cooling aperient, gently opening bowels. In large doses (1 to 2 tablespoonfuls) is a hydrogogue cathartic, causing free, watery stools.

Creosote, Beechwood (poison).—Useful in toothache; 1 to 2 drops on a piece of absorbent cotton introduced into the clean cavity, care taken that it does not come in contact with the gums, tongue, or cheek. Do not use internally.

Dobell's Solution.—Useful as an antiseptic wash or spray for nose and throat in nasal catarrh and bronchitis.

Epsom Salt.—Useful in constipation and dysentery. Dose: 1 to 2 tablespoonfuls dissolved in as little water as possible. A little lemon juice and sugar may be added to disguise somewhat its bitter taste.

Essence Jamaica Ginger.—Useful in cramps, colic, indigestion, and gas in stomach. Dose: 1 teaspoonful in sweetened water.

Essence of Peppermint.—Useful in cramps, colds, gas in stomach, and colic. Dose: 10 drops to ½ teaspoonful in sweetened water or on sugar. Externally is useful in rheumatism, neuralgia, and toothache.

Flaxseed Meal.—Useful as hot poultice to apply to boils and felons. Compresses wet with hot bichloride solution, 1 tablet to 5 pints of hot water, are better. To prepare flaxseed poultice a receptacle containing boiling water should be placed on the fire, the flaxseed meal should be gradually added and constantly stirred until the batter is jellylike. This should be evenly spread, with a thickness of from ¼ to ½ inch, to within 2 or 3 inches of the border of a cloth prepared for that purpose by folding in two or three layers. To prevent the poultice from adhering to the skin any of the following may be placed on its surface: Gauze, mosquito netting, cheesecloth, vaseline, or sweet oil.

Formalin (poison).—Used as a disinfectant generally in connection with permanganate of potash, as follows: For every 1000 cubic feet of room space to be disinfected use ½ pound of permanganate of potash, powder or crystals, and from 1 to 1¼ pints of formalin. Add the permanganate of potash to the formalin contained in a deep tin pail. Effervescence begins at once, the room is tightly closed, and the operation is over in about 10 minutes. After 12 hours the room is opened and the odor removed by sprinkling ammonia.

Glycerin.—Is a mild and healing application for sores, chaps, etc. When mixed with an equal quantity of water is useful in earache, hard, irritated, or feverish skin, chapped face or hands, split lips, and chafing.

Iodide of Potash (5-grain tablets).—Useful in syphilis. Dose: 1 tablet dissolved in water three times a day after meals.

Laudanum (poison).—Useful in easing pain in dysentery and cholera morbus. Dose: 5 to 30 drops.

Lead and Opium Wash (poison) (shake well before using).—Soothing external application in sprains and bruises.

Lemon Juice.—Useful in fevers and inflammatory complaints. Hot lemonade on retiring is useful to aid in the relief of a cold in its first stages.

Lime Water.—Internally is useful in soothing sick stomach, heartburn, diarrhea, and in dyspepsia attended with acidity of the stomach. Dose: 1 to 3 tablespoonfuls. For sick stomach, to be repeated after each effort to vomit. Externally as liniment (mixed with an equal quantity of linseed, cottonseed, or olive oil) for burns and scalds.

Magnesia, Calcined, Heavy.—Useful in sick headache, dyspepsia, sour stomach, and heartburn. Dose: ½ to 1 teaspoonful one hour after meals, and, being mildly laxative, for constipation in doses of ½ to 1 teaspoonful.

Menthol.—Useful in oily solutions (menthol 3 grains, liquid petrolatum 1 ounce) as cooling drops in nose in colds in the head. Ten drops should be placed in each nostril with a medicine dropper.

Mustard.—Externally is useful to draw the blood to the surface in case of pain where skin is not broken. Should be employed as a plaster or poultice, made as follows: 1 part of mustard is thoroughly mixed with from 2 to 4 parts of flour and made into a paste by the addition of a small amount

of tepid water. This is then spread thinly to within 1 or 2 inches of the border of a cloth prepared by folding in two or three layers of old cotton cloth. The amount of mustard depends upon the degree of pain, the age of the patient, etc. Care should be taken that the mustard does not blister the skin. As a rule, mustard plasters or poultices should not be applied to children and old people, as they may blister the surface. Internally given to produce vomiting, 1 tablespoonful stirred to a cream with a cupful of tepid water.

Oil of Cloves (poison).—Useful in toothache, being applied the same as creosote. (See above.)

Olive Oil (sweet oil).—Internally is useful in constipation. Dose: 2 to 3 tablespoonfuls. Externally is a soothing application to blistered, burned, scalded, or other injured surfaces, also to piles.

Oil of Wintergreen (methyl salicylate).—Useful when mixed with an equal amount of olive oil, as an application for the relief of neuralgia, rheumatism, and painful joints. The oil should be gently rubbed on the painful area. If used about the head care should be taken that none gets into the eyes.

Paregoric (poison).—Useful in quieting cough and relieving pain in the stomach and bowels and to check diarrhea. Dose: 1 to 2 teaspoonfuls.

Permanganate of Potash.—Useful in gonorrhea as an injection; ¼ teaspoonful dissolved in 2 quarts of water. One teaspoonful to a quart of water makes an efficient wash for perspiring feet. Useful in snakebites in the form of a concentrated solution which should be injected freely and immediately into and around the part which has been bitten. Useful as a general antiseptic in solution (1 tablespoonful dissolved in a quart of water). As a disinfectant, see "Formalin."

Peroxide of hydrogen solution is cleansing and slightly antiseptic. Useful as a gargle in sore throat, diluted with an equal quantity of water. Useful to apply to wounds, boils, and abscesses, after diluting with from 1 to 3 parts of water.

Picric Acid (poison).—Dissolve in water (½ per cent. solution). Useful to wet dressings with, as an application to burns.

Quinine Sulphate (5-grain tablets).—Useful in malaria, colds, and as a general bitter tonic. Dose: 1 tablet three times daily. Dose as tonic: ½ of a tablet three times a day.

Salicylate of Soda (5-grain tablets).—Useful in rheumatism, neuralgia, and headache. Dose: 1 to 2 tablets every three hours.

Salol (5-grain tablets).—Useful in diarrhea, dysentery, rheumatism, and fermentative dyspepsia. Dose: 1 tablet three times a day.

Syrup of Ipecac.—Useful in croup, bronchitis, cough, and hiccough. Dose: 10 drops every three hours. Also used to produce vomiting in doses of 1 to 2 tablespoonfuls.

Soap Liniment (for external use only).—Useful in rheumatism, sprains, and bruises.

Spirit of Camphor.—Internally is useful in nervous diarrhea, colic and cramps. Dose: 5 to 30 drops, first added to sugar and then mixed with water.

Strychnine Sulphate (poison) (1/60 grain tablets).—Is a bitter tonic and stimulant and is useful in anemia and dyspepsia. Dose: 1 tablet three times a day.

Sun Cholera Mixture (poison) (15-minim tablets).—Useful in diarrhea, dysentery, and cholera morbus. Dose: 1 tablet.

Sweet Spirit of Niter.—Useful in fevers, flatulent colic, and colds. Dose: ½ teaspoonful in sweetened water every four hours.

Tannic Acid (tannin).—Useful in hemorrhages from external surfaces or from mucous membrane which can be reached from without. Applied either pure or in solution in water or glycerin. Useful as an application wherever powerful astringent action is needed.

Tincture of Green Soap.—Cleansing hands.

Tincture of Iodine (poison, for external use only).—Useful to disinfect wounds; should be diluted with an equal quantity of alcohol or water. If painted over inflamed surfaces, will sometimes be of value.

Tincture of Iron.—Useful as a tonic. Dose: 10 drops largely diluted with water, three times a day. Rinse mouth after taking. Should be taken through a straw.

Tincture of Myrrh.—Useful in diseased gums and sore throat. Directions: For spongy and bleeding gums, apply with a sponge or soft brush. For sore throat, use as a gargle, 1 teaspoonful in a cupful of water.

Turpentine.—Used in the form of hot turpentine stupes in typhoid fever, pneumonia, colds, bronchitis, lumbago, pleurisy, and inflammation of the bowels. The stupes are prepared by wringing a double layer of thin flannel out of a pint of hot water with which a teaspoonful of turpentine has been mixed. These applications should not be prepared too close to a fire on account of the inflammability of the turpentine.

Unguentine.—Useful in burns, scalds, and inflammation. Spread on linen or cotton cloth and apply.

Vaseline.—Internally and externally useful for the relief of cold in the chest. Externally useful in cold in the head, soothing irritated surfaces, burns and scalds, and as a protective dressing.

Zinc Sulphate (poison).—Useful in gonorrhea as an injection, made in the proportion of ¼ teaspoonful to 1 pint of water. Is given internally in doses of ¼ to ½ teaspoonful dissolved in water to produce vomiting.

COMMON SICKNESS

Stomach and Bowels	Fevers	Throat and Lungs	Miscellaneous
Constipation	Typhoid fever	Sore throat	Headache
Stomach ache	Marlarial fever	Pneumonia	Sunstroke
Diarrhea			Rheumatism
Dysentery			Influenza
			Gonorrhea
			Nephritis
			Piles
			Poison ivy

In case of serious sickness get the patient to a settlement where he can receive proper nursing and medical care.

CONSTIPATION

Constipation should be promptly corrected. Mild cases will generally respond to cathartic pills. Epsom salts can be used or a couple of tablespoonfuls of castor oil.

Obstinate cases require injections of warm water with olive or castor oil

COLIC (STOMACH ACHE)

Mild cases can be treated with 10 drops essence of peppermint or a teaspoonful of Jamaica ginger in hot water.

Obstinate cases often require an injection to clear the bowels and a dose of 10 drops of laudanum in water taken internally; if the pains persist a second dose of laudanum can be repeated in two hours.

DIARRHEA AND DYSENTERY

Mild diarrhea caused by poor diet will generally respond to a mild laxative (cathartic pills or castor oil). The diet should consist of light articles such as weak broths, soft boiled eggs, milk and thoroughly toasted bread. The patient should remain in bed if the attack is at all severe and in this case after the bowels have moved freely in response to the cathartic if the diarrhea or pain continues give one camphor and opium pill repeated after three hours if necessary.

DYSENTERY

Dysentery occurs in its most dangerous form in the tropics but will respond as a rule to immediate treatment.

Cause.—Bad food, unripe fruit, impure drinking water, exposure to cold and dampness while probably not the direct cause are contributary to the disease.

Prevention.—Boil all drinking water and be careful of diet. Avoid extreme exposure.

Symptoms.—May or may not be chills. Some fever. Tongue furred and moist, then red and dry or brownish and glazed. First stools like simple diarrhea. Soon are simple mucus or a mixture of blood and mucus. Patient complains of colicky pains in his belly and a burning sensation in the rectum and constantly desires to go to stool.

Treatment (Health Bulletin No. 17).—Rest in bed. Stop all solid food. Give 2 tablespoonfuls of castor oil and 15 drops of laudanum in one dose and if necessary repeat the dose in six hours. After the bowels have been thoroughly cleared out, give a pill of camphor and opium every three hours.

Hot applications should be placed on the abdomen. Washing out the rectum with a pint of warm water and then injecting 2 ounces of thin starch containing 25 to 30 drops of laudanum will relieve the burning sensation.

After two or three days if the disease continues the castor oil may be again given, the treatment repeated.

Diet should be limited to thin porridge milk and broths. Patient must be kept warm in bed in even light cases.

TYPHOID FEVER

Cause.—Typhoid fever is a contagious disease. It is generally contracted by drinking infected water or milk or eating food that has been prepared by a person just recovering from the disease.

Prevention.—Care in regard to water and milk supply.

Symptoms.—Headache, diarrhea, cramps in the abdomen, nosebleed, loss of appetite, coated tongue, dry mouth and fever which is higher each day than on the day previous. The stools are foul smelling and of the consistency of pea soup.

Duration.—Four to seven weeks. Convalescence is slow.

Treatment (U. S. Health Bulletin No. 17).—Place the patient in bed and do not let him get up. When he desires to have an action of the bowels, the bedpan should be used. He should have a liquid diet, plenty of water, milk, and thin soups, which should be given in liberal quantities, a cupful every two hours; no solid food should be allowed until 10 days after the fever has subsided. The temperature should be watched and the patient bathed with cold water whenever the fever rises above 39° C. (102.2° F.). Ice-bags, if obtainable, applied to his abdomen and chest will assist in keeping the temperature down. One should also be applied to the head if there is delirium. If there is distension of the abdomen hot turpentine stupes should be applied. This is done by wringing a double layer of thin flannel out of hot water with which a teaspoonful of turpentine per pint of water has been mixed. An injection of a pint of warm water containing a teaspoonful of turpentine is also beneficial. The bowels should be kept open by injections of warm soapy water. In case of collapse give coffee or inject hot coffee or salt solution (one teaspoonful of salt to a pint of water) into the bowel.

MALARIAL FEVER

Cause.—Malarial fever is caused by germs generally transmitted by the bite of mosquitoes.

Prevention.—Protect bed by mosquito bars. Avoid location of camp near stagnant pools or other features favorable to mosquito breeding. In localities where malarial fever is prevalent take 6 grains of quinine every day. This is an important preventative measure.

Medical authorities state that the use of quinine as a preventative has reduced the number of cases per 1000 men per year from 275 to 50.

Treatment (Health Bulletin No. 17).—When a chill occurs, the patient should at once be wrapped in blankets and be given hot drinks. Hot-water bottles, heated bricks or stones wrapped in cloth or in a separate piece of blanket, should be placed at the feet. Mustard plasters may also be applied to the extremities and over the region of the heart.

During the hot stage cold drinks may be administered; if it is severe a tepid bath in a tub or by means of a sponge may be given. If the temperature is very high, 105° or 106° F., a cold bath should be given.

As soon as the sweating stage begins 10 or 15 grains of quinine should be taken, and along with this, if the bowels are not freely open, a calomel tablet, one-tenth grain each, should be given every 15 minutes until 10 have been taken. Every six hours thereafter the patient should take 5 grains of quinine for two or three days and then 5 grains three times daily for the next two weeks.

If vomiting occurs, a mustard plaster may be placed over the region of the stomach, above the navel, and cracked ice may be given by the mouth. Headache may be relieved by cold applications or by 10 grains of aspirin taken with a cup of hot tea.

In pernicious types of malarial fever the treatment should be more active. No time should be lost in giving the quinine; 20 grains should be given immediately, with 2 grains of calomel. A physician should be summoned if the services of one can be obtained, as dilute solutions of quinine may have to be injected into the patient's veins in order to save his life.

SORE THROAT (TONSILLITIS, QUINSY)

Sore throat is a common disease. It is usually the result of exposure to wet and cold. Talking, laughing, or shouting in a damp, cold atmosphere is sometimes the cause of it. It may accompany or be an extension from an ordinary "cold in the head." It is a complication of diphtheria, scarlet fever, smallpox, tuberculosis, and syphilis. It is caused also by drinking milk drawn from cows with sores on their teats. Sometimes the inflammation is limited to the mucous membrane of the pharynx and soft palate; it is then known as pharyngitis or acute catarrhal sore throat. More frequently the tonsils are affected, and the inflammation is then called tonsillitis. When the inflammation is more deeply seated behind the tonsil and tends to suppurate or form an abscess, the term "quinsy" is applied. An attack of sore throat may last from 2 to 10 days, or longer.

Symptoms of acute sore throat are chilliness and feverishness, pain or soreness on swallowing, dryness, or a tickling or scratching sensation in the throat.

There is liable to be stiffness and some tenderness along the side of the neck. If one or both tonsils are involved, as they usually are to a greater or less extent, the symptoms are more severe. In marked cases examination shows redness and swelling of the parts affected—swollen tonsils (tonsillitis) and white or cream-colored spots may be seen on the surface of one or both tonsils. (This form of the disease is frequently mistaken for diphtheria.) There may be high fever and great prostration.

In the severest form of tonsillitis (quinsy) the tonsil is hard and swollen to twice or three times its natural size, and the patient is unable to swallow or to open his mouth beyond a fraction of an inch. The saliva dribbles away; if suppuration occurs the tonsil gradually softens until the abscess breaks. With the discharge of pus the severe pain is relieved and the patient rapidly recovers. If the abscess is large, and if the pus is discharged in a backward direction, there is danger from suffocation, particularly if the abscess breaks during sleep. Fortunately the abscess usually points toward the mouth, and the pus runs out.

Treatment.—Persons who are subject to attacks of sore throat should keep their feet dry and be careful not to catch cold. If a case develop, give a gargle of salt water or potassium chlorate and water (saturated solution), or boric acid and water may be applied to the tonsil. Dry bicarbonate of soda (baking soda) is highly recommended as a local application, a small quantity to be applied every hour. Apply cold water or a light ice-bag to the neck, or a thick piece of flannel saturated with ice water may be placed around the neck and covered with muslin. Small pieces of ice placed in the mouth are usually agreeable. The bowels should be kept open by means of Epsom salt.

If the cold applications to the neck do not give relief, or if they are not agreeable to the patient, apply hot water or poultices and give hot gargles, or let the patient gargle with hot tea. If the swelling is very great, he can not gargle. If practicable, send for a physician.

INFLUENZA

The disease begins like a cold. There are pains in the head, eyes, an limbs; a watery discharge from the nose, chilly sensations, sore throat, cough, and extreme muscular prostration. The sputum is of a dirty yellowish color. There may be abdominal symptoms such as nausea, diarrhea, vomiting, and cramps. There is fever, which varies according to the intensity of the disease. There are many varieties of the disease, and any organ of the body may be attacked. Pneumonia is a frequent complication.

Prevention.—Care should be taken that no one suffering from the disease coughs in your face. Keep away as much as possible from such persons. A cold in the head or on the chest may be due to the influenza bacillus, so do not sleep with persons suffering from these conditions.

Treatment.—Aspirin, 5 grains every three hours, often relieves the pains. A mild purgative such as a Seidlitz powder should be given. The tendency to diarrhea should be remembered, so strong purgatives such as salts should not be administered. When there is pain in the abdomen a camphor and opium pill is of value. A light diet such as milk and soups should be taken. Steaming the nose and throat by inhaling steam from a teapot filled with hot water into which a small lump of camphor has been dropped will relieve to some extent the congestion of those structures.

PNEUMONIA[1]

Cause.—The germ responsible for the disease is generally conceded to be present in the bodies of all healthy people but only causes sickness when the resistance of the victim is lowered for some reason. Chilling after extreme exertion and long-continued exposure to cold often bring on the trouble.

Symptoms.—Severe chill, high fever, difficult breathing and pain in the chest. The sputum is abundant, and is a rusty brown. The pulse is at first full and later weak and rapid. The fever in typical cases lasts for 7 to 9 days and then in favorable cases drops to normal in a few hours.

Treatment.—The essential feature of the treatment of pneumonia is to see that the patient gets plenty of cold fresh air. Oftentimes no other treatment is necessary. The bed should be placed upon a porch, or, if this is impossible, all the windows of the sick room should be wide open. The patient should be well covered, and hot-water bottles or hot bricks should be placed near his feet to keep them warm, care being taken not to burn him. Once a day the patient should be moved to a warm room and given a sponge bath. The pain in the side can be relieved by a mustard plaster (p. 453) or by the administration of one-fourth of a grain of morphine sulphate. Two grains of calomel and four grains of sodium bicarbonate followed, in about six hours, by a Seidlitz powder should be given on the first day, and the bowels should be kept open thereafter by a small dose of salts given each day. The patient's strength should be conserved by giving him a glass of milk or a bowl of soup every two hours during the day, and also at night when he is not sleeping. Solid food should not be given, as it will cause gas in the stomach, which may press against the heart and seriously interfere with its action. Milk is the best food, but sometimes it produces gas, in which case soups alone should be used.

HEADACHE

Headache is not a disease in itself; it is the symptom of some other disease and if it occurs frequently a physician should be consulted.

Treatment.—Temporary relief can often be obtained by taking 10 grains of aspirin repeated in three hours if necessary. Open the bowels with a cathartic.

POISON IVY

Treatment.—Bath with salt water or a boric acid solution, 1 teaspoonful in a glass of hot water. Open the large blisters and let the water out. Every day bath the infected areas with warm water, dry without rubbing and apply the boric acid solution.

SORE EYES

Inflammation of the Membrane Covering the Eye.—Caused by grit, dust, exposure to cold, etc.

Symptoms.—Eye painful. Eyeball red and lids swollen. Pain increased by exposing eyes to light. Water runs from eyes.

Treatment.—Wash eyes out every two hours with boric acid solution (1 teaspoonful of acid in a glass of warm water). A few drops of zinc sulphate solution (½ grain to 1 ounce of water) should be placed in the eyes every three hours.

SUNSTROKE

Cause.—Prolonged exposure to strong rays of the sun or high humid temperature.

Prevention.—Proper head and spine protection under tropical sun and avoidance of travel under extreme conditions of heat. Drink water sparingly. Oatmeal water quenches thirst in small quantities.

There are two varieties of trouble.

No. 1.—Heat stroke (heat fever) in which the body temperature is high.

No. 2.—Heat prostration in which the surface of the body is cool sometimes below normal.

The difference is very important as the treatments are radically different.

Symptoms and Treatment

No. 1 Heat Stroke.—Severe cases the victim may fall unconscious and die instantly. The usual case manifests intense headache, dizziness, nausea,

[1] Briefed from Health Bulletin No. 17.

vomiting and hot skin. Temperature may reach 105° F. Pulse full and may be either slow or rapid. Patient sinks into stupor and unconsciousness. They may recover under treatment or die within twenty-four hours.

Treatment (heat stroke).—Reduce temperature of body at once by cold water bath, ice pack on head till temperature of body as shown by a thermometer in the rectum is reduced to 100° F. If the temperature rises again repeat the treatment.

If the patient is exhausted after the reduction in temperature give strychnine sulphate 1/40 grain.

No. 2 heat prostration with a cool skin and weak rapid pulse stimulants are required. Wrap patient in blankets, hot-water bottles at feet and around abdomen; give 1/40 grain strychnine sulphate. If head is hot, cold-water pack can be applied to head only. If vomiting occurs inject hot salt water solution into rectum (1 tablespoonful of salt to 1 pint of water).

MUSCULAR RHEUMATISM

In this disease the muscles most frequently affected are those of the back (lumbago), side of neck (stiff neck or wry neck), and side of chest (pleurodynia). Exposure to cold, sudden cooling of the body—especially after active exercise and sitting in a draft of air—are the chief causes or exciting causes.

As a rule there are no symptoms other than the stiffness and pain on motion. The muscles may be slightly swollen and very sensitive. Sometimes the attacks come on suddenly and apparently without cause, or following a slight twist or strain, as a "kink in the back," or patient may wake up in the morning with a stiff neck.

In treating acute cases salicylate of soda or aspirin may be given in 5- or 10-grain doses every three hours until four or six doses are taken. Apply hot applications, dry heat, hot-water bag, or a hot poultice locally, or the heat may be applied by a flatiron over folds of flannel or a piece of blanket and the rheumatism "ironed out." Later apply liniment with friction (massage). Keep the affected muscles at rest. If the muscles of the chest are affected, apply strips of adhesive plaster, the same as for fractured rib. Acute attacks are of short duration, but relapses are not uncommon, and chronic forms are frequently met with. Good food, fresh air, and attention to the general health are especially important in the treatment of chronic muscular rheumatism.

ACUTE RHEUMATISM (RHEUMATIC FEVER)

This is a comparatively common disease in all climates within the Temperate Zone. It occurs chiefly during the winter and spring. Exposure to a cold, damp atmosphere is the most frequent exciting cause in persons predisposed to the disease.

It may or may not begin with a chill or with a sore throat. The larger joints are usually affected. Swelling, heat, redness, tenderness, and pain are the chief symptoms. The inflammation is apt to shift from one joint to another. The pain and fever are usually increased in proportion to the number of joints involved. The majority of cases are attended with profuse perspirations, scanty, highly acid urine, coated tongue, and constipation. The heart is frequently involved.

In treating, wrap the joint in cotton or flannel; keep it very quiet—the slightest movement aggravates the pain. Flannel wrung out of hot water and applied to the joint sometimes affords relief. A liniment composed of 10 to 50 per cent. of oil of wintergreen in olive oil may be applied on a piece of flannel if the pain is severe, or cold applications may be employed if agreeable to the patient.

Place the patient in a good bed, and let him wear flannel next to his skin. Change the flannel frequently, and bathe the body with tepid water.

For internal medication give salicylate of soda or aspirin in doses of 10 grains every two hours until about eight doses are taken or the pain is relieved; then give it in smaller doses of from 3 to 5 grains every six hours.

The food should be soft and nourishing and given every three hours. Epsom salt should be given to keep the bowels open. The patient should be kept in bed for a few days after the symptoms have subsided. The duration of the disease is very uncertain. The acute symptoms may subside in a few days and the patient may be up and about in a week or 10 days, but relapses are common, and the acute may pass into the subacute or chronic form.

GONORRHEA (CLAP)

Treatment (Health Bulletin No. 17).—Rest in bed, light diet, plenty of water to drink, regularity in eating and sleeping. Keep the bowels open by taking a moderate dose of Epsom salt in the morning. Avoid strong coffee and tea, all stimulants, and greasy articles of food. Keep the body and mind at rest. Bathe frequently in hot water. Be very careful not to carry any of the pus from the urethra to the eyes. (Gonorrheal inflammation of the eyes is a serious disease, which not infrequently results in total blindness.)

Give a copaiba capsule three times a day. If much pain in the back or over the region of the kidneys follows the use of the copaiba, it must be discontinued for a time or the dose lessened.

Injections of silvol 5 parts, water 90 parts; argyrol, 10 per cent. solution; permanganate of potash 1 part, water 5000 parts; or sulphate of zinc 1 grain, water 1 ounce, into the urinary canal may be used. They should be employed as follows: The patient first passes his water, the urinary canal is then washed out with several syringes full of warm water. One of the above solutions is then injected slowly into the canal and held there five minutes by the watch. The best syringe for this purpose is one made of glass, having a plunger wrapped with cotton thread. If a testicle swells, apply cloths wrung out of cold water, or an ice-bag. Rub the affected part with the following mixture: Oil of wintergreen (10 drops) and olive oil (1 teaspoonful). If chordee is troublesome, apply cloths wrung out of cold water.

PILES

Cause.—Often due to chronic constipation.

Prevention.—Keep bowels regular and easy.

Treatment (U. S. Health Bulletin No. 17).—In acute attacks, if the bowels are constipated give a full dose of Epsom salt; put the patient on light, soft diet. Apply ice to the anus or inject cold water into the rectum. An ointment composed of 5 grains of menthol mixed with 2 tablespoonfuls of vaseline often affords great relief. If the piles protrude, especially if they become strangulated, they should be pushed back with the finger; olive oil, or vaseline may be applied. If the piles are large and persistently painful, see a surgeon and have them removed by operation, which is the only sure cure.

KIDNEY DISEASE (ACUTE NEPHRITIS)

Cause.—Expose to cold and dampness.

Symptoms.—Amount of urine is materially reduced. Generally the color is dark red or brown and contains albumen which can be detected by boiling a teaspoonful with a few drops of vinegar. The presence of albumen is shown by a cloudy precipitate in the boiled urine. Other symptoms may be headache, vomiting, diarrhea, convulsions and unconsciousness.

Treatment.—Put patient to bed, keep him warm and in acute cases induce sweating by hot blankets, etc. Put him on a milk diet and give him all the water he wants. Keep the patient as quiet as possible and after the albumen has disappeared from the urine avoid cold, dampness and excessive exercise for some time as convalescence is slow. During convalescence avoid eating red meats.

FIRST AID FOR ACCIDENTS

As mentioned on page 445 all the data on *First Aid* are quoted from Bulletin No. 17 by the courtesy of the department which was glad to coöperate to make the data available for emergencies.

CONDENSED INDEX

U. S. HEALTH SERVICE BULLETIN NO. 17

By Surgeon R. M. Woodward

Rules to be Observed in Time of Accident

1. Give the patient air.
2. Lay the patient down, head lower than the body.
3. Rip the clothes off the injured part.
4. In removing a coat or shirt, first release the good arm, then the injured one.
5. Turn the head to one side to allow vomited matters to escape from the mouth.
6. Do not give whisky to the patient. If he can swallow, and needs a stimulant, give coffee, tea, hot milk, or hot water.
7. Then follow directions given elsewhere in this book.

A LIST OF DON'TS

Don't fail to send for the doctor. He knows best.

Don't leave the patient in order to go for the doctor if there is any one you can send. He may need your moral encouragement if nothing more.

Don't get excited. An appearance of agitation on your part will discourage the patient.

Don't hold an injured person on his feet, nor require him to sit in a chair. He will be better off and less apt to faint if he lies down, preferably with the head low.

If you have a first-aid chest, and a bottle of medicine is exhausted, don't wait until you need it again before having the bottle filled.

Don't put your fingers on a wound. They are covered with germs, and you will almost surely infect the wound.

Don't use a spider web or a quid of tobacco on a wound. They are filthy, do no good, and are very apt to infect the wound. The same thing is true to a less extent in regard to salves of various kinds.

Don't place cotton next to a wound. Always keep at least one layer of gauze or boiled cloth between the cotton and the raw surface. The cotton sticks to the wound and is very difficult to remove.

Don't apply bandages too tightly.

Don't remove a dressing to see how a wound looks. Let the doctor do that.

Don't sit down at the bedside and discuss with the callers all of the horrible accidents you ever heard of. Your conversation will not be appreciated by the patient.

MINOR ACCIDENTS

Bruises, sprains, foreign matter in eyes, ears, nose and throat.

BRUISES AND CONTUSIONS

A bruise or contusion is an injury where the tissues beneath the skin have been torn but the skin itself has not been opened. Blood oozes out of the injured vessels, but can not escape, as the skin is still intact. The symptoms are swelling, tenderness, and a feeling of soreness or pain. Discoloration of the skin occurs quickly in superficial contusions and in places where loose tissue abounds, but only after days when the injury is deep-seated. This discoloration is at first red and then, successively, purple, black, green, and yellow. This play of colors is due to the changes which take place in the blood while undergoing absorption.

Treatment.—A pad of gauze or soft towel should be tightly bandaged over the injured part to stop hemorrhage, after which cold should be applied except in old or feeble persons or where the contusion is extensive. In the latter case heat is best, as cold might cause gangrene. Evaporating solutions, such as witch-hazel, a 15 per cent. solution of alcohol in water, or a saturated solution of Epsom salt, are often found of great benefit. A contusion should never be opened except in rare cases when it is necessary to stop persistent bleeding. If an opening is made through the skin, germs are liable to enter and cause severe inflammation, resulting in the formation of pus.

Sprains.—A sprain in a stretching or wrenching of a joint. The joints most frequently affected are the ankle, wrist, knee, and shoulder.

The symptoms and signs are pain, swelling, impairment or loss of motion, and discoloration from effusion of blood. When there is much swelling it may be difficult to determine whether sprain or fracture, or both, are present.

As explained under "Broken Bones," page 484, it is sometimes very difficult to determine whether an injury near a joint is a sprain, a bruise, a broken bone, or all combined; and if there is doubt, the case should be treated as a broken bone. Injuries about the ankle-joint are especially confusing, and sometimes the *x*-ray shows a fracture that could not have been detected in any other way. It should also be understood that a sprain, particularly if some of the soft parts about the joint are torn, may be much longer in being restored to a normal condition than if a simple break of the bone had occurred without other injury.

Treatment.—Either hot or cold applications are good first aid measures, but they should be distinctly either hot or cold, and not tepid. Soaking the part for half an hour several times a day in water as hot as can be borne, and gently rubbing the skin, are excellent. If it is more convenient to apply a bag of ice, this can be used, but the heat and cold should not alternate. Propping the part up on pillows assists. If there is much pain, great relief is obtained by surrounding the joint with a thick layer of cotton and applying a plaster bandage. The circulation of the lower part of the limb should be watched, and if found to be impaired the bandage should be cut from above downward and the sides spread apart to relieve any constriction that may be present. After the swelling has subsided somewhat, rubbing with any kind of liniment or with alcohol will help, but it is the rubbing more than the liniment that does the good.

It is popular belief among laymen that a large quantity of liniment, perhaps applied on flannel cloth, is all that is necessary, and that the rubbing is only of secondary importance. This is a decided mistake. Later on the part should be grasped and gently moved in various directions, making what is known as passive motion. In some cases this is inadvisable and the patient appears to do better with the part at rest, which can be obtained by strapping the joint with strips of sticking plaster or placing the limb in a splint. The black and blue condition of the skin that sometimes appears will gradually subside as the part gets better.

FOREIGN BODIES IN THE EYE, EAR, NOSE AND THROAT

Foreign Bodies in the Eye.—When a piece of steel, a cinder, or any foreign body enters the eye, nature at once floods the eye with tears in an endeavor to wash the offending agent away, and frequently succeeds. Sometimes, however, the foreign body is embedded in the eyeball, the lid, or other part of the eye, or keeps moving about from one part to another without escaping; then assistance is necessary.

Occasionally drawing the upper lid well down with the fingers, and allowing the lashes of the lower lid to act as a brush, will remove the body if it is not tightly embedded. Usually, however, it is necessary to invert the upper lid; in other words, turn it inside out. This is not difficult with a little practice. The upper eyelid contains a piece of cartilage or gristle along its lower edge which makes it easy to turn. To invert the eyelid face the patient, or stand behind him as seems more convenient; have hiim look well down toward the floor; take hold of the lashes of the upper lid with the fingers and thumb of one hand; they lay entirely across the middle of the eyelid a wooden toothpick, match, knitting needle, lead pencil, or other thin object (Fig. 89); press it downward, and at the same time gently pull the lashes upward, when the lid will suddenly turn inside out (Fig. 90). Drawing down the lower lid by simply pressing upon it will expose its inside surface. If the foreign body is seen, it should be very gently removed with the corner of a handkerchief. If it is partly embedded in the eyelid, it may be possible to gently dislodge it with a wooden toothpick or other similar object. If the foreign body is on the eyeball, it sometimes requires a good light, good eyesight, and even a magnifying glass to detect it. If found, it should be removed with a handkerchief or other soft material, but if embedded too tightly to be removed in this manner, it is best for the layman not to attempt anything further for fear of greater injury to the eye. Under such circumstances one or both of the eyes should be snugly bandaged with soft light proof material, such as red flannel, and the doctor should be called as soon as possible. The patient should be cautioned not to wink his eyes, as all motion will increase the irritation.

If you have succeeded in removing the body, and the eye appears very red, a little sweet oil, dropped in will be very soothing. It should be remembered that the scratching of the eyeball makes it feel as if the body were still present after its removal. The old household remedy of dropping a flaxseed into the eye in the hope that in slipping about it may dislodge the body is said by specialists to do no good, and may do harm.

Foreign Bodies in the Ear.—Children occasionally place buttons or similar objects in the ear. If near the outlet, they can sometimes be removed (in the absence of suitable instruments) by gently passing along one side a crochet needle or other similar implement. It should oe remembered, however, that the drum of the ear, which is extremely delicate, and means so much to the child in the future, is only a short distance inside, and any effort of this kind made by the layman should be very gentle indeed. A stream of water from a small syringe may wash the object out. If these measures do not succeed, wait for the doctor by all means. Sometimes an insect crawls into the ear. The actual physical danger is less than the mental

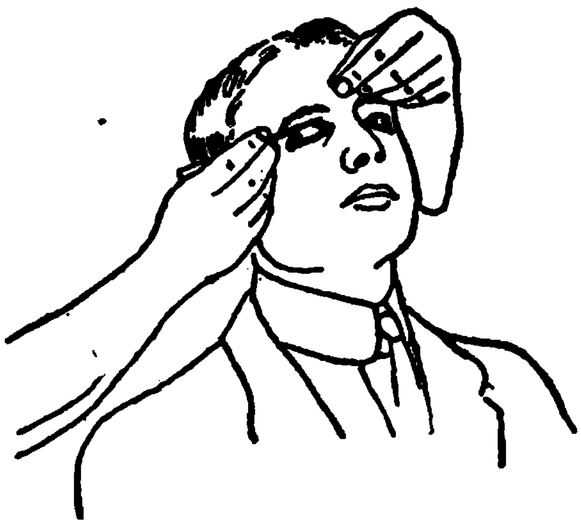


FIG. 89.

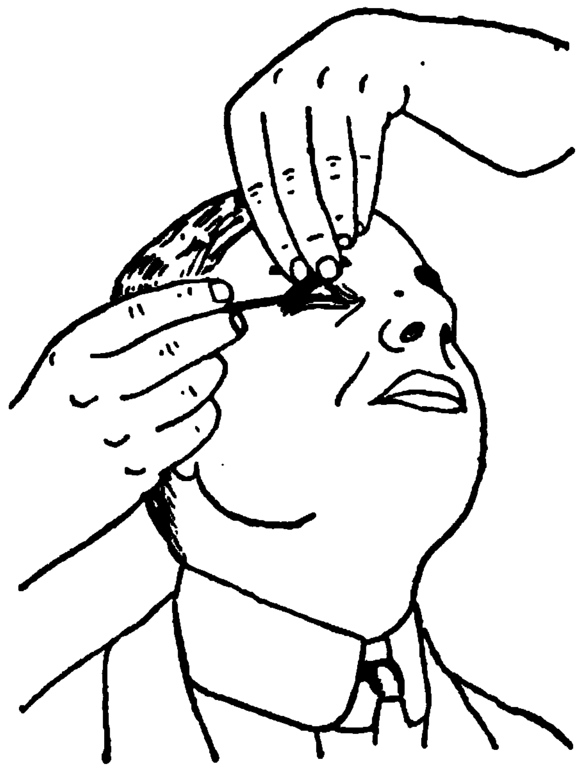


FIG. 90.

horror, as the insect soon dies. A little sweet oil dropped into the ear may cause the insect to back out to free itself from the unpleasant predicament; if not the oil will kill it.

Foreign Bodies in the Nose.—If near enough to the nostril to be seen the body may possibly be expelled by compressing the other nostril and having the patient blow his nose hard. A fountain syringe placed 1 foot above the head, the nozzle of the syringe inserted in the clear nostril and the patient's face looking somewhat downward, will cause the water to gently flow in at one side of the nose and out at the other side, and may dislodge the object. A crochet needle may be gently tried as described for the ear. All these things failing, wait for the doctor.

Foreign Bodies in the Throat.—If the body can be seen by holding the tongue down with a spoon or by drawing the tongue out with a towel, it can sometimes be hooked out by means of a finger passed well in. If the body is in the windpipe, this will be manifested by violent coughing, which may dislodge it. Inverting the patient and slappng his back may be tried. If these measures do not succeed, then use every effort to quiet the patient, and if practicable send for a physician. If the body is in the gullet on the way to the stomach, vomiting may bring it up, and this can be excited by tickling the throat, or using some of the simple vomiting agents mentioned in the data on poisons (page 481) provided the patient can swallow. If it is not dislodged, and is known to be an object without sharp edges, as a coin, for instance, it is best to induce it to go on into the stomach by drinking water, eating bread, mashed potatoes, or other soft food. Once in the stomach the patient, usually a child, should be made to eat all the mashed potatoes he can possibly hold, and a large dose of castor oil should follow. The potatoes form a mass around the foreign body, and the oil usually pushes this mass through the bowels without any trouble what-

ever. The stools or passages should be carefully watched to determine that the object passes, and if it does not, the doctor should be consulted without delay.

SERIOUS ACCIDENTS—FIRST AID

BITES AND STINGS OF POISONOUS ANIMALS OR INSECTS

Snake Bites.—(Do not give alcohol or ammonia.) Poisonous snake bites must receive instant treatment. Fasten a bandage or handkerchief above the wound and twist it tight to prevent the flow of blood toward the body and heart. Cut the wounded flesh out so that it bleeds freely. If there is anyone with you get them to suck the wound immediately, thoroughly and repeatedly spitting out the blood and washing their mouth with water eliminates all danger to them. A concentrated solution of potassium permanganate should then be poured into the wound or better injected around and above the wound using the full charge held by an ordinary hypodermic syringe. (When working in a snake country a small pocket case containing a sharp clean lancet, hypodermic syringe and a bottle of potassium permanganate should always be carried). The tight bandage cutting off the flow of blood must be loosened within ten minutes of its application to permit some circulation as a long continued stoppage of blood causes gangrene even when the blood is allowed to circulate freely at intervals of ten to fifteen minutes the tight bandage should be removed entirely within a couple of hours. There is great danger in its prolonged use. Snake bites treated promptly in this way are rarely fatal although they may make the victim very sick. The patient's vitality should be prompted by hot blankets, water bottles, etc.

Wilson's Topographic Surveying states that in addition to this treatment the only sure cure particularly for the more dangerous tropical snakes is the hypodermic injection of *Antivenene serum*. "The injection is made in the cellular tissue of the right or left side of the abdomen. Treatment should be immediate for best results although it may be successful after as much as three or four hours. If there is time the skin should be carefully cleansed before using the syringe, the needle of which should be inserted deeply closely compressed with the fingers for a couple of minutes and then hastily withdrawn.

"Antivenene serum can be obtained from Les Establissements Poulenc Freres, 92 Rue Vieille-du-Temple, Paris. The serum will keep for years. Dose 10 cc.(contents of one flask), or for large snakes as the cobra 20 cc. or two full doses at once."

Bite of Dog or Cat.—This is usually a punctured wound; that is the teeth enter without tearing the flesh, and the wound almost entirely closes, thereby preventing drainage and increasing the danger. Sucking the wound hard repeatedly and washing out the mouth with hot water may remove some of the poison. Squeezing is less effective. The wound should then be burned either with carbolic acid or a red-hot iron carried to the bottom, and the skin about the wound should be scrubbed with alcohol or other antiseptic. A drain of several strands of boiled sewing silk should be pushed into the bottom of the wound, and an antiseptic dressing or boiled cloth applied over the wound. The patient should then be taken to the nearest place where the Pasteur treatment to prevent hydrophobia or rabies can be secured. The hygienic laboratory of the United States Public Health Service in Washington, D. C., administers this treatment without cost.

If the animal is known to be mad this treatment is imperative, and whether mad or not it is a very wise precaution and relieves the anxiety of the patient.

BLEEDING (HEMORRHAGE)

Kinds of Blood-vessels.—There are two kinds of blood-vessels. Those that carry the blood from the heart to all parts of the body are called arteries. The blood in them is bright red, and escapes in jets or spurts corresponding to each beat of the heart. Bleeding from these is more dangerous and more difficult to control, as a rule, than bleeding from the vessels that return the blood to the heart. Fortunately, however, the larger arteries in the limbs lie near the bones, and are consequently well protected in most parts by the mass of muscles covering them. The vessels that return the blood to the heart are called veins. They contain a darker blood than the arteries, and when cut, the blood escapes in a steady stream, not in spurts. While

the largest veins in the limbs are also near the bones, there are some of considerable size just under the skin.

If we should desire to stop a stream of water flowing past a given point, we would naturally go upstream from that point and not downstream to adopt the necessary measures. When there is bleeding from an artery, the blood coming from the heart, the artery must be compressed at a place between the heart and the bleeding point. On the other hand, if a vein is bleeding, the blood flowing toward the heart pressure must be made on the vein at a place farther from the heart than the bleeding point.

Bleeding, General Treatment.—Before beginning the treatment of any wound or any bleeding point, if there is time, the operator must carefully cleanse his hands and arms, and also the wound and surrounding parts. The instruments and silk ligature should be boiled, as described under the head of wounds.

In the after treatment of severe bleeding the patient should be kept perfectly quiet in mind and body, his head should be lowered by raising the foot end of his bed or bunk. Give him plenty of fresh air, keep his body

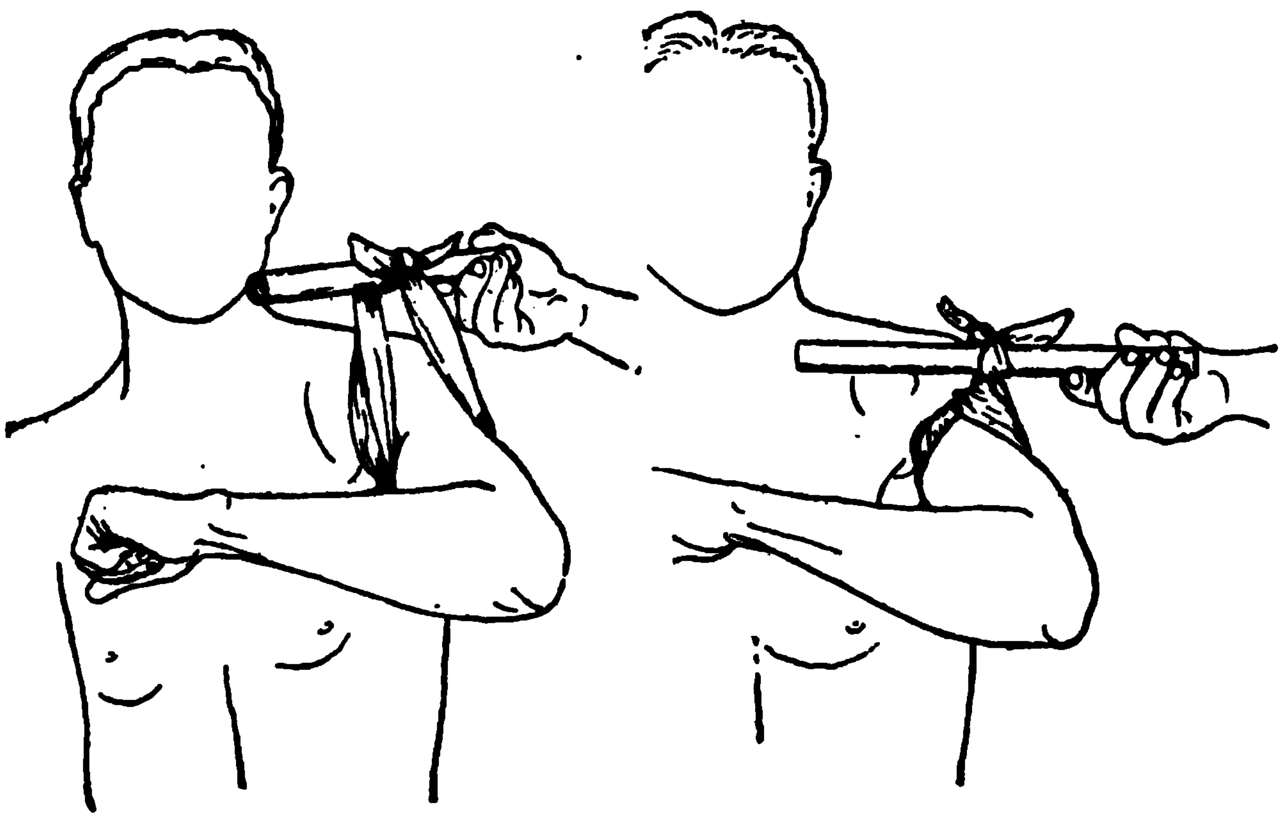


FIG. 91. FIG. 92.

warm and give him hot drinks. After reaction the temperature of the body may rise a degree or two above normal, but if this should continue longer than two or, at most, three days, the dressing should be removed and the wound thoroughly irrigated, first with hot water, then with a solution of bichloride of mercury (1 to 5000) and dressed with aseptic gauze.

Bleeding from Arteries.—There are certain places in the body where the arteries are not covered by much muscle, and can be easily compressed against bone. These places are shown in the illustrations. The bleeding should be controlled first by thumb pressure at the points indicated in the illustrations, and if the services of a doctor can be secured without delay, this will be all that is necessary until he arrives. If there is any doubt as to the exact place at which pressure should be made, a slight shifting of the thumb from one point to another should be made rapidly, and when the bleeding stops it indicates that the proper location has been reached and pressure should be continuous at this point. If a doctor is not within reach, the bleeding must of course be controlled by some other device. When the bleeding is from one of the limbs, and some distance from the body, a bandage or clean handkerchief should be wrapped around the limb at the point indicated by a cross in the illustrations (Figs. 93 to 102) and drawn tight enough to stop the bleeding. The "Spanish windlass" (Figs. 91 and 92) is made by knotting a handkerchief around the limb loosely, passing a stick through the slack part, and taking up the slack by twisting

the handkerchief. To prevent untwisting, the stick is then bound to the limb by one or two other bandages or handkerchiefs. A small round stone, a cork, or other similar object placed in the folds of the handkerchief and lying directly over the vessel will assist. Only sufficient pressure should be made to barely stop the bleeding. The windlass must be loosened every 20 minutes to give a chance for the blood to flow through the part, as there is great danger of gangrene (mortification) if the blood is entirely shut off for longer than this time.

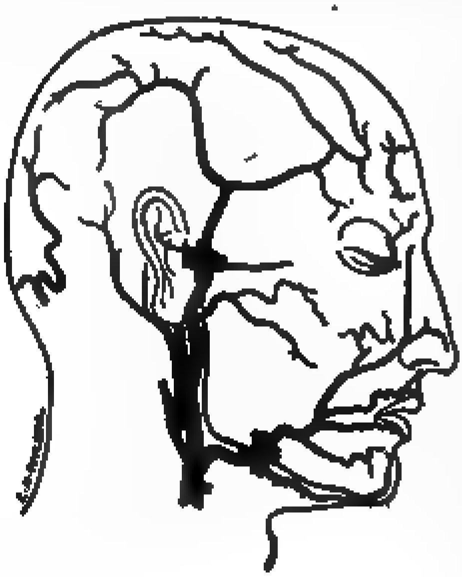


FIG. 93.

The knot in the windlass should not be untied, and the stick should be left in position for immediate tightening if the blood again begins to flow freely. If the windlass is to be used for several hours, it is best to encircle the limb with a folded towel before applying it, as there is less danger of injuring the skin and soft parts. If the bleeding artery is in or near the body, where a windlass can not be applied, thumb pressure must be kept up until the doctor arrives, one person relieving another. The second person's thumb should gradually push the first person's thumb aside, and thus prevent a spurt of blood. In exceptional cases it may be necessary to place the thumb directly in the wound to control the bleeding, but, no matter how clean the thumb may be, this should only be resorted to in desperate cases, as there is great danger of infecting the wound. Reference is made in this connection to the chapter of antiseptics.

In places where the services of a physician can not be obtained, the wound should be stretched open, the blood-vessel located, seized, and drawn gently forward with a pair of artery forceps and the ends tied with heavy

FIG. 94.

thread that has been boiled for five minutes. If artery forceps can not be obtained, take a needle or a bent pin, pass it through a flame several times, hook onto the vessel, and draw it out; then tie it tightly with the thread described above. If a little flesh is tied in the knot with the artery, this

will be of no consequence. After the artery has been securely tied the "Spanish windlass" should be removed, or, if thumb pressure has been employed, this should be discontinued. The wound should then be closed as described under the heading "Wounds."

Bleeding from Veins.—The deep veins as a rule follow closely the course of the arteries. If thumb pressure on the far side (the side farthest from the

Fig. 95.

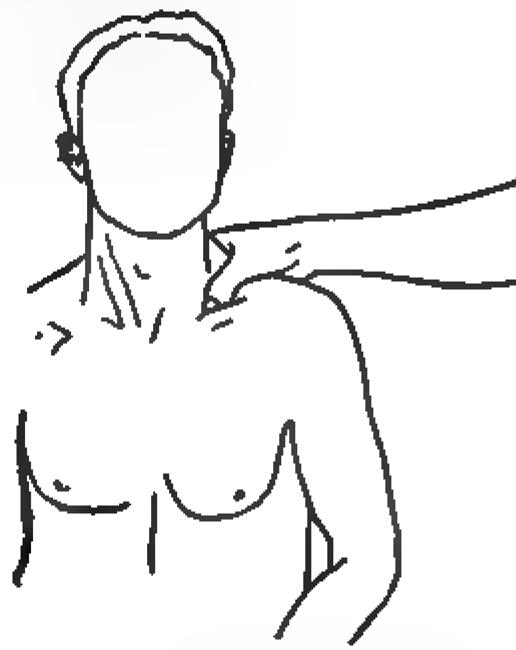


Fig. 96.

Fig. 97.

Fig. 98.

heart) of the bleeding point fails to control the bleeding, a Spanish windlass should be applied on the far side. If the bleeding vein is near the surface, it may be possible in some cases to control it by a windlass with a stone or cork, the windlass not being drawn tight enough to shut off the deeper vessels. In some cases bleeding from veins is best controlled by pressure directly over the bleeding point, but the thumb should be covered by a clean

cloth, such as a handkerchief or towel. Elevation of the part and removal of all constricting bands, such as garters will assist.

Where there is simply an oozing of blood and it does not appear that any vessel of size has been severed the case can frequently be controlled by

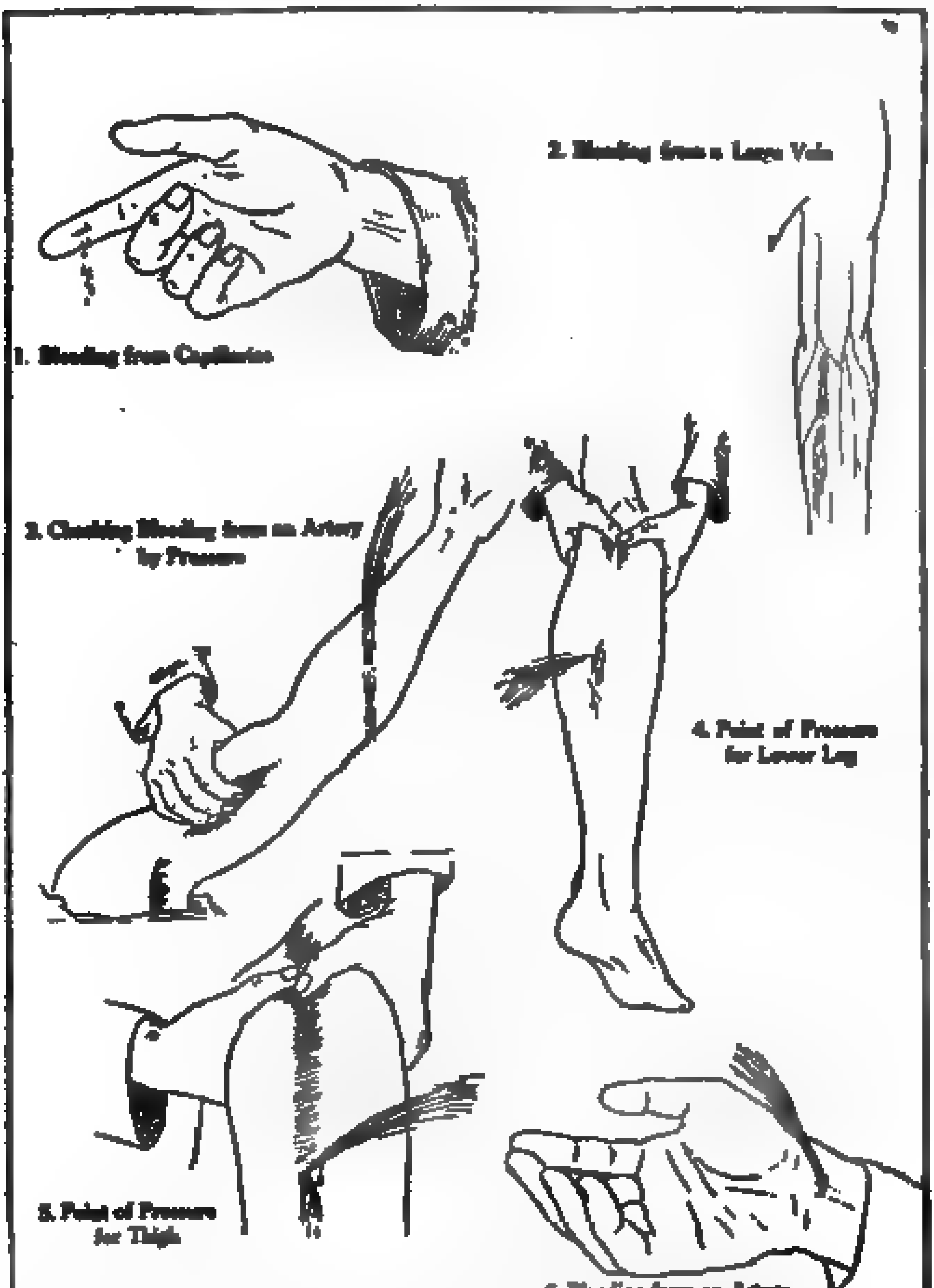


Fig. 99.

steady pressure of the bleeding surface. Sometimes cloths soaked in water as near the boiling point as can be borne and constantly changed will accomplish the result. If peroxide of hydrogen is at hand, it is one of the best known agents to stop simple oozing.

Bleeding from Head and Face.—Reference to Fig. 93 will show a po in front of the ear, compression upon which will control bleeding about t temple. Another important point for pressure is shown where the arte crosses the edge of the lower jawbone. This controls bleeding in the pa

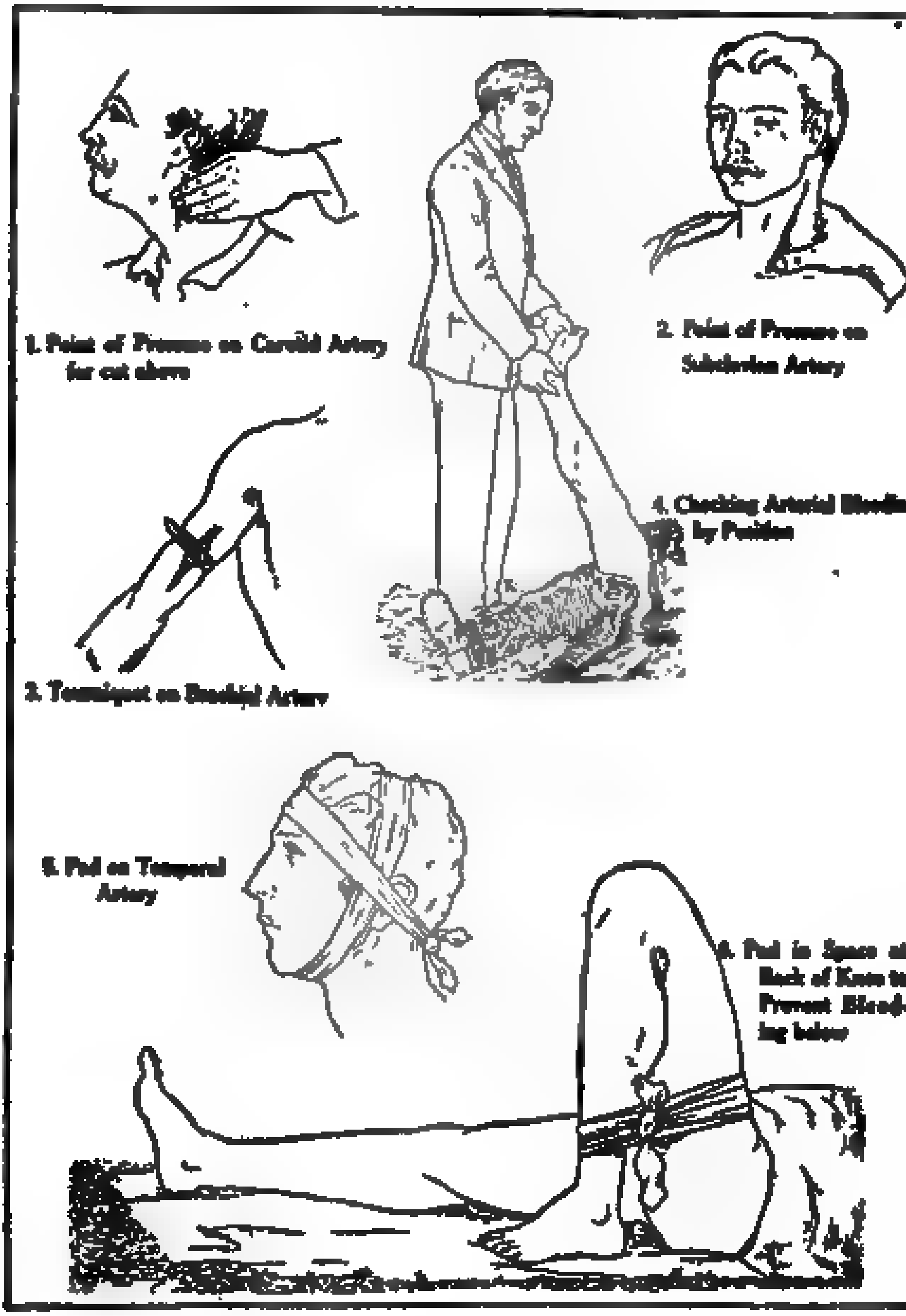


FIG. 100.

supplied by this artery, as shown in the illustration. If the bleedin severe and it is evident that a larger and deeper vessel is responsible, i necessary to compress the large artery in the neck. If you will turn y own head well toward one shoulder, say the right, you will be able to on the left side a strong muscle standing out under the skin and extend

from a point just back of the ear to the point where the left collar bone joins the breastbone. This is your guide to the deep artery. Pressure should be made deeply between the lower end of this muscle and the windpipe, compressing the artery directly against the backbone (Figs. 94 and 95).

Bleeding from Shoulder.—If the bleeding is in the neighborhood of the shoulder joint, the artery to be controlled is the one lying directly under the collar-bone. Pressure is made downward, behind the collar-bone, near the point where it joins the breastbone, the artery being compressed against the rib (Figs. 94 and 96).

Bleeding from Arm, Forearm, and Hand.—If you place your left hand on your right arm between the shoulder and elbow and then bend the right elbow and straighten it out several times, you will feel a muscle swell up in the arm and subside again. Extending along the inner edge of this muscle and close to the bone a large artery can be felt beating (Figs. 97 and 98). This is the one to compress when bleeding is from a point in the arm or forearm. If the forearm, the best place to compress this last mentioned artery is just above the elbow; and is also the best point if there is severe bleeding in the hand.

Bleeding from Thigh or Leg.—In the groin, halfway between the hip bone and the middle line of the body, the main artery supplying the thigh and

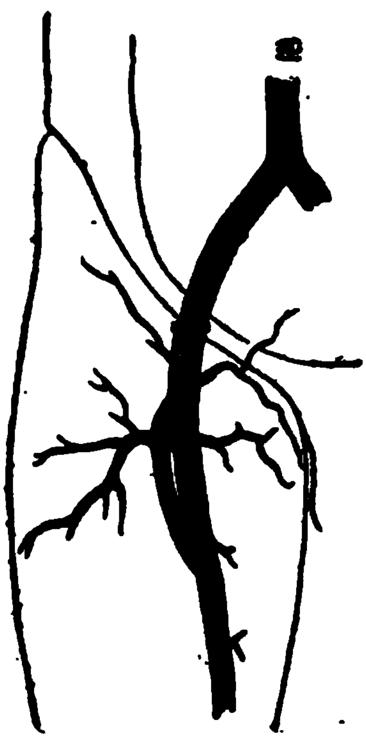


FIG. 101.

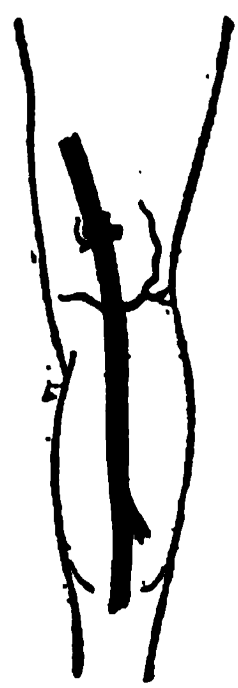


FIG. 102.

leg can be pressed against the bone (Fig. 101). If the bleeding is from the back of the knee, the leg, or foot, the best place to apply pressure is just above the knee at the back of the thigh (Fig. 102).

Bleeding from Lungs and Stomach.—If the blood is from the lungs, it is generally coughed up and has the bright red appearance of ordinary blood. If from the stomach, the acid of the stomach juice changes the blood until it has more the appearance of coffee grounds. If, however, the bleeding is severe, the vomited blood may be bright red, as the acid of the stomach may not have had time to act upon it. Sometimes blood brought into the throat from the lungs is swallowed by the patient and later vomited in its changed condition.

In the treatment of either of these conditions, it is best to keep the patient very quiet in bed, let him suck small pieces of ice in limited quantity, and apply cracked ice in some waterproof covering over the chest or pit of the stomach, as the case may be. Cheerfulness and an encouraging attitude on the part of the attendants are necessary.

Bleeding from the Nose.—If bleeding of the nose occurs in a full blooded person, especially if such person is subject to dizziness, we should not be in too much of a hurry to stop it. But if the bleeding is the result of injury or if it occurs in a person suffering from disease of the heart or lungs or

from the effects of malarial fever, scurvy, or any disease of the general system, effort should be made to stop it. Nosebleed from a blow, in a healthy individual, usually stops in a short time without any particular treatment. If it does not stop, place a piece of paper folded to the thickness of a quarter of an inch well up between the upper lip and gum, and compress the lip tightly against it. The main blood vessels supplying the nose pass upward from the corners of the mouth to the sides of the nose, and this paper tends to compress the vessels and shut off the blood supply. The patient should lie on his back with his head on a pillow. If ice is obtainable, it should be cracked into small pieces, wrapped in a thin cloth, and placed over the nose, a sufficient quantity being used to cover the whole surface. Cold applied to the back of the neck will also do good in some cases. If the bleeding is obstinate, a strip of gauze or soft cloth can be pushed gently into the nostrils, the ends being allowed to hang out.

Bleeding from the Urinary Canal.—This is usually caused by falling astride of a hard object. The bleeding may be profuse, but is usually controlled by pressure with a folded towel. If the bleeding is severe, a stick with a cross-piece at one end should be placed at the foot of the bed, the cross-piece pressing against the towel in the crotch. After the bleeding ceases, the patient should be kept quiet and cold applications should be used.

BURNS AND SCALDS

Burns.—Burns or scalds are serious and dangerous to life in proportion to the extent and depth of the injury. A burn covering a large area and producing mere reddening and swelling of the skin is as serious as a burn one-half the size in which the skin is destroyed. The danger is from shock, from fever following reaction, from hemorrhage following sloughing, and from congestion and inflammation of internal organs. Burns of slight extent or moderate degree are not so dangerous, and most of the cases commonly met with will recover. But all cases require careful treatment.

Treatment.—The indications for treatment in these two conditions are virtually the same if the damage is superficial; and this is usually the case, the injuries being only skin deep. Blisters should be pricked with a needle that has been passed through a flame several times. This allows the water to escape from the blisters, but the skin raised by the blisters should not be removed. If the burning agent is pitch or tar, and adheres to the skin, it should not be removed; it will come away later with the blistered skin. Any bland oil, such as sweet oil, linseed oil, or vaseline, forms a soothing application. Ordinary baking soda or a saturated solution of soda in water can be used. The old "Carron oil" made of linseed oil and lime water, half and half, is excellent, but has an unpleasant odor. If lime water is not at hand, it may be obtained as follows: Quicklime is first slaked by adding to it gradually about 30 times its weight of water. Agitate during one-half hour, allow the lime to settle, and reject the liquid. Add to the residue of lime about 300 times its weight of water, agitate frequently during the next 24 hours, and allow the lime to settle. The clear water standing above the undissolved lime is lime water.

The parts burned or the entire body, except the head, may be kept immersed in tepid or warm water for days. Cream or white of eggs may be used, but they are apt to become offensive after 24 hours. Kerosene is an old household remedy. One teaspoonful of table salt in a pint of water makes a solution that can be employed. Keep the patient quiet and his bowels active. Pain or restlessness may be relieved by laudanum 20 drops, repeated in two hours if necessary.

If the eye is red from contact with the flames or hot fluid, sweet oil is perhaps the best household remedy to drop in. A bandage lightly applied over the eyes to keep out the light will be soothing.

If the skin or the eye is burned with acid, a solution of baking soda should be used first. If the burning agent is an alkali, such as hartshorn or lye, weak vinegar or lemon juice should be used. Sweet oil should be dropped in the eye after such treatment.

If the patient has breathed the flame or steam the condition is apt to be a serious one, even though it does not appear so at once. Complete rest and quiet, an ice-bag to the chest, the giving of milk and cream, half and half, if swallowing is possible, should be employed. Artificial respiration, as described elsewhere, may be applicable in some cases.

Speaking generally of burns and scalds, a superficial burn covering a

large part of the skin may be more dangerous than a deep burn confined to a small part, for reasons which it is unnecessary to discuss in a book of this kind. No burn or scald should therefore be treated as a trivial matter. Where solutions are used the bandages should be soaked in the same before applying and the solution should be poured over the bandaged part at frequent intervals.

Paraffin mixtures have been recently used extensively for the treatment of burns. The mixture is melted and then sprayed upon the burned surface. It is then covered with a layer of gauze and more of the mixture is sprayed on. Instead of spraying, the mixture may be painted on the surface with a sterile brush. The mixture becomes hard when it cools, forming a protective coating for the burn. The paraffin should be removed once a day, the wound washed with a weak antiseptic solution, dried with pellets of gauze or cotton, after which another coat of the paraffin mixture is applied. Melted wax may be employed instead of paraffin. In either case a coating of liquid petroleum or kerosene should be applied to the wound before the wax or paraffin is used.

The scars resulting from burns and scalds always contract, and in severe cases terrible deformities are produced. These may be prevented to some extent by active and passive motion and by splints.

EFFECTS OF COLD-FROSTBITE

Frostbite.—Severe cold depresses the action of the heart, suspends the circulation. These effects are first noticed in the ears, nose, fingers, and toes. Numbness and tingling are the first symptoms, then loss of sensation. If not too long exposed, the circulation may be restored by proper treatment. But if the exposure is long continued or if the cold is very intense the parts are hopelessly frozen and gangrene will be the result. The parts may look all right for a few days after reaction and then become discolored, bluish, and finally black. Another effect of extreme cold is an overpowering sense of drowsiness, but to lie down and go to sleep under such circumstances is almost certain death.

Treatment of Frostbites.—1. Do not bring the patient to the fire until the circulation is restored in the frozen part.

2. If snow be on the ground or accessible, take a woolen cloth in the hand, place a handful of snow upon it, and gently rub the frozen part until the natural color is restored. In case snow is not at hand bathe the part gently with a woolen cloth in the coldest fresh water obtainable, ice water if practicable.

3. In case the frostbite is old and the skin has turned black or begun to scale off do not attempt to restore its vitality by friction, but use the treatment for burns described on page 471.

4. In the case of a person apparently dead from exposure to cold friction should be applied to the body and the lower extremities and artificial respiration practised as in case of the apparently drowned. As soon as the circulation appears to be restored administer strychnine sulphate one-fortieth grain. Even if no signs of life appear friction should be kept up for a long period, as instances are on record of recovery after several hours of suspended animation.

ANTISEPSIS, ANTISEPTICS, AND THE DRESSING OF WOUNDS
(Health Bulletin, No. 17)

We are surrounded at all times by very minute organisms capable of producing various diseases or complications. They are sometimes called germs, and more vulgarly called "bugs." The latter name is incorrect, as the germs belong to the vegetable and not the animal kingdom. In first-aid work the germs that particularly interest us are those that get into wounds and infect them, causing pus or "matter" and sometimes blood poison.

Definitions.—When these complications arise the process is known as "sepsis." "Antisepsis," therefore, refers to the question of removing or killing the germs, and "antiseptics" are the medicines or other agents used in accomplishing these purposes. This explanation is made for the reason that it is necessary to use the terms "antisepsis" and "antiseptics" in this chapter, there being no common names quite so expressive. There is another term, "asepsis" used by doctors, which refers to the condition

where all germs have been removed or killed, but this is a condition that does not often obtain in first-aid work administered by a layman, and therefore will not be further discussed. We frequently hear a person say that he has good blood because when he cuts himself the wound heals quickly. This is apt to give him a false sense of security and cause him to neglect the precautions that should be taken. Some of the worst cases of "sepsis" and blood poison occur in strong healthy men who have had no previous trouble in the healing of wounds. Germs are always present on the skin and can be demonstrated by laboratory methods. They can only be seen by a microscope of high power. A patient may have taken a hot soap bath before being injured, but his skin is not surgically clean, and antiseptics are therefore employed to destroy the germs that remain.

The Dresser's Hands.—The one who is to make the dressing should see that his own hands are surgically clean before he attempts to clean or "sterilize" the wound; otherwise he is apt to transfer germs from his hands to the wounds or to the dressings. The hands should be scrubbed with a nail-brush, hot water, and soap. Then the finger nails should be cleansed and the hands scrubbed again. A good way to clean the finger nails is to rake them across a cake of soap, filling the space under each nail with the soap. As this is removed with a pocketknife the dirt comes away with it. Then after the second scrubbing the hands should be soaked and rubbed in some antiseptic solution and not dried. The skin about the wound should now be scrubbed with the nailbrush and soap; and if it is a hairy part, the hair should be shaved for some distance on all sides of the wound before the scrubbing. The wound and the parts about it should then be thoroughly cleansed with the antiseptic solution; and a cloth, preferably one that has been boiled, soaked in the antiseptic solution, laid over the wound, and bound there with a bandage.

Alcohol.—The antiseptic that is most apt to be at hand or most easily obtained is alcohol. It should be diluted with water, making a mixture of 1 part water and 3 parts alcohol. It creates a burning sensation when applied to a wound, but this is a small matter if it prevents infection in the wound. Where alcohol can not be obtained, whisky or brandy, which contains about 50 per cent. of alcohol, may be obtainable. Some experiments have recently been made in the San Francisco Federal Laboratory by officers of the United States Public Health Service showing that whisky and brandy are very good antiseptics.

Iodine.—Tincture of iodine, usually known by the layman as simply "iodine," is one of the best antiseptics known at the present time. Its power is far greater if applied to a dry surface than to a wet surface. The burning sensation produced in the wound does not last long. A dry sterile dressing over it is preferable to a wet dressing, as the wet dressing lessens its power and is apt to blister the skin. Too much iodine may also blister, and it should therefore be diluted with an equal part of alcohol.

Bichloride of Mercury.—An antiseptic much used in hospitals is bichloride of mercury or corrosive sublimate. It is not apt to be on hand in the ordinary household or camp, but is mentioned as one of the agents to be kept in the first-aid chest. It can be purchased in tablet form, and each tablet added to a pint of water makes a solution of a certain strength (see page 449). This strength that is safest for the layman to use is 1 part of bichloride of mercury to 5000 parts of water. This is an excellent antiseptic. It is a deadly poison, however, if taken internally, and should therefore be handled with care.

Peroxide of Hydrogen.—Peroxide of hydrogen has become a favorite and popular antiseptic. Its power in this regard is weak, but it is a cleansing agent and can be employed as a dressing in the absence of anything better. It tends also to stop oozing of blood in a wound where no large vessels are cut.

Carbolic Acid.—The pure carbolic acid should be obtained if possible, and as a dressing for wounds should be made into a solution of 1 part of carbolic acid to 100 parts of hot water.

Compound Cresol Solution.—This is a very serviceable antiseptic solution, as it readily dissolves in cold water and is as powerful as carbolic acid solutions of the same strength. It may be employed in 1 per cent. solutions for any purposes for which an antiseptic solution is required. It is especially good for sterilizing instruments, as it does not injure them.

Sterile Dressings.—There can be purchased for the first-aid chest various kinds of sterile dressings; that is, dressings that have had all germs killed

by exposure to heat. Sterile gauze comes packed in a box in the form of a roll, and it unrolls as pieces are drawn out and cut off. From a theoretical standpoint the gauze is no longer sterile after the package has once been opened, but for practical first-aid work it answers the purpose if each piece cut off is carefully unfolded with clean hands and the inside of the piece applied next to the wound. It is advisable to buy small packages, so that a new one will be opened from time to time.

How to Sterilize Dressings.—The one most efficient and always available method of sterilizing dressings is by boiling for 10 minutes in plain water, which, from a practical standpoint, kills all germs that can infect a wound. If a dry dressing is desirable it can be placed in a pan in a hot oven for 15 or 20 minutes and removed just as it is beginning to be scorched. If several layers of a sterile dressing are applied directly over a wound and lapped around it at all sides, it is not absolutely necessary that the additional dressing material placed over this be sterile, although it is desirable.

Sterilizing Instruments, etc.—If scissors, knitting needles, ordinary needles, or other metal instruments or implements are necessary in dressing a wound, they should be boiled in water for 10 minutes, or can be passed through a flame several times, or some alcohol can be poured on the instrument and then set on fire with a match. Actual fire is apt to remove the temper from the instrument much more easily than boiling, for which reason boiling is preferable.

Treatment of Wounds.—Doctors divide wounds into several classes, namely, incised, lacerated, contused, punctured, poisoned, gunshot and infected. The nature of the first three is sufficiently clear from their names and from a first-aid standpoint may be considered together. The first thing to do is to control severe bleeding by pressure on the wound or upon a distant part of the blood vessel, as explained in the data on "Bleeding." Then, after the dresser has disinfected his own hands, the wound should be thoroughly cleansed and disinfected; these matters will be explained in "Antiseptics." Iodine, if at hand, is the best agent to use. If the wound is on a hairy part, as the scalp, the hair should be shaved for a distance of several inches from the wound. An antiseptic dressing should then be applied, or in the absence of any such agent one may use a clean cloth boiled for 10 minutes in clear water or in water to which table salt has been added in the proportion of 1 teaspoonful to the pint. This dressing is retained by a bandage and should not be disturbed for any reason except bleeding if the doctor can be reached within 48 hours.

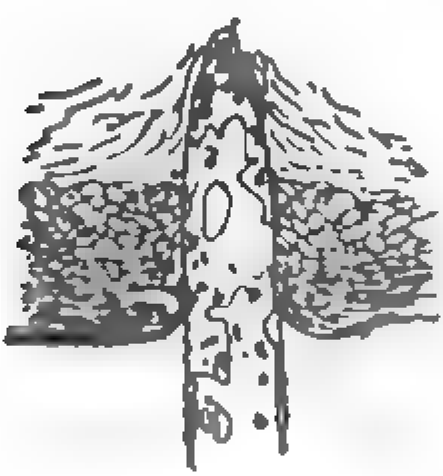


FIG. 103.

If it is impossible to secure the services of a doctor for several days and the wound gapes to such an extent that it can not be readily closed by bandaging or is in a part where a scar will mean disfigurement, the layman may attempt to close the wound by stitching, and this can be done by using an ordinary sewing needle with silk or linen thread, both boiled for 10 minutes, the needle being pushed through the flesh by means of a thimble, also boiled. The stitches should pierce the skin about an eighth or quarter of an inch from the edge of the wound and come out of the fleshy part of the wound about the same distance from the skin. They should be placed about half an inch apart, and each one should be tied and cut off. The stitches should only be drawn tight enough to barely close the wound, because the swelling may make them too tight. No wound should be closed by a layman without leaving drainage, that is, something that will lead off the bloody water that oozes from a wound.

A piece of boiled sewing silk or linen folded back and forth and then twisted until it makes a skein one-eighth of an inch thick should be laid in the bottom of the wound and allowed to hang out at the lower end for a distance of an inch. This drains by capillary attraction, and there is far

less danger of blood poison than if the wound were closed tightly. This drain should be removed after 24 hours by simply drawing it out without disturbing the stitches. The stitches themselves should be left in place from three to six days, depending principally upon the depth of the wound and its tendency to gape. The stitching of a wound should only be attempted by a layman when a doctor can not be reached within 48 hours.

The closure of a wound by sticking plaster is a questionable expedient, because it seals the wound, prevents drainage, and blood poison may follow. If the wound is not large, a strip of boiled cloth may be laid directly over it and the wound then drawn together by strips of sticking plaster applied outside the cloth.

Whether the wound is closed by stitches or not, the layman should apply an antiseptic dressing, if such is available, and if not, a boiled cloth, as described above, can be used.

A badly contused or bruised wound should not be stitched by a layman. In a lacerated wound it may be necessary to trim off with boiled scissors a few ragged edges of skin before stitching.

If a wound has penetrated the belly and the bowel is protruding, it is best not to attempt to push it back if the doctor can be reached within a few hours. It should be gently washed with the salt solution, described elsewhere (page 474), and kept covered with towels frequently wet with the same solution. If a doctor can not be reached within a few hours, and the person in charge of the patient after a careful examination is sure that the bowel has not been opened or otherwise seriously injured, he should, after carefully washing the bowel with the salt solution mentioned above, return it to the belly. If the bowel is allowed to remain for too great a time outside of the belly, its circulation may be cut off by the pressure of the belly walls and gangrene result. If the bowel has been opened or severely bruised, it should not be returned, as there is danger of forcing fecal matter out of the bowel into the belly cavity, which would cause a dangerous inflammation. If the bowel is not protruding from the wound, simply treat as an ordinary wound.

Punctured Wounds.—A punctured wound is one made by a piercing agent, such as a nail, tack, knife, or needle. Such a wound is dangerous, because it almost completely closes and does not drain. If germs are introduced at the time of the accident, they can not escape. A wound of this kind, except of the chest or belly, should be disinfected or burned, and the best agent is pure carbolic acid. In the absence of suitable instruments a knitting needle or other thin blunt implement should be dipped into the carbolic acid and then inserted to the full depth of the wound. This should be repeated several times. The first application causes a burning sensation, but the acid itself soon deadens the part, and the subsequent applications are less painful. If the knitting needle is then dipped in alcohol or whisky and inserted once or twice and a little is applied to the skin about the wound, it will stop the burning action of the carbolic acid. In the absence of the carbolic acid the alcohol or whisky can be used alone, but are far less efficient. After this treatment an antiseptic dressing or a boiled cloth should be applied to the wound. The frequency with which lockjaw follows punctured wounds, particularly nail wounds, makes it imperative that the doctor be consulted promptly and that the wound be not regarded as trivial because it is small in size. An injection of serum (tetanus antitoxin) will prevent lockjaw.

Poisoned Wounds.—The principal poisoned wounds met with are those due to bites of animals or bites and stings of insects, and these will be considered under a separate heading (see page 464).

Gunshot Wounds.—A gunshot wound is similar to a punctured wound in that it is small and almost completely closed. If the ball has passed entirely through a part, as the leg, and has not struck an important vessel or broken a bone, the wound is apt to cause less trouble than one in which the ball remains in the flesh. If a portion of clothing is found in the mouth of the wound, it should be removed. The part should be well cleansed with soap and hot water and an antiseptic dressing or a boiled cloth applied. Further than this it is not best for the layman to attempt anything, particularly probing for the bullets. If a bone has been broken by the ball, the case should be treated as described under "Compound Fracture."

Infected Wounds.—A wound should never be permitted to become infected, but it is not always possible to prevent it, as germs may be introduced at the time of the injury by the weapon causing the injury or on pieces

of cloth or in dirt carried in with it. Badly contused wounds are also liable to become infected as the devitalized tissue is unable to resist the attack of harmful bacteria. Continuous or frequent irrigation with an antiseptic solution has been found to be the best method of thoroughly cleansing wounds of this kind and to keep them free from bacteria. A very weak bichloride solution (1 to 15,000) may be used for this purpose, or, even sterile water containing one teaspoonful of salt to the quart may be employed if nothing else is available. The Dakin-Carrel solution, is however, the best for this purpose. Tablets for the preparation of this solution, known under the trade name of Chlorazene Tablets, can now be obtained in the drug stores. In order to be effective, the solution should be introduced to the bottom of the wound. A special apparatus is employed for this purpose. Gauze is packed around rubber tubes after they are placed in the wound. Only enough solution to keep the dressing damp should be allowed to flow into the tubes. A modification of this solution has recently been made in which oil is used instead of water. This makes it unnecessary to be continually wetting the gauze as the oil keeps the wound moist for a longer period and the wound need therefore be dressed but once a day.

RESUSCITATION FROM APPARENT DROWNING

In the act of breathing, the oxygen from the air is absorbed from the lungs into the blood vessels and purifies the blood; at the same time the impure matters picked up by the blood in circulating through the body are filtered out by the lungs and pass off to the atmosphere with the breath. When a person is under water he can hold his breath for a short time, keeping out the water; then he swallows some water into the stomach, and as his strength fails water enters the lungs. The water in the stomach does no particular harm; but that in the lungs is of vital importance because it stops breathing, causes poisoning of the system from lack of purification of the blood, and if allowed to remain for any length of time produces stoppage of the heart and death.

The indications, therefore, in one apparently drowned are to remove the water from the lungs, to make the patient breathe, and to stimulate the weak heart.

The old method of rolling a patient over a barrel to remove the water from the lungs is not considered efficient by those who have had most experience. Inverting the patient by grasping his feet and holding him head down for a few moments, at the same time making pressure on his belly inward and toward the chest, may remove part of the water. The chest is separated from the belly by a partition consisting of a thin flat muscle, and pressure inward and upward on the belly forces this partition up against the lungs and may mechanically squeeze some water out of the tubes in the lungs. Time should not be wasted in prolonged efforts to remove the water, as it is important to proceed as quickly as possible with artificial breathing, which will not only squeeze the water out of the lungs but will renew respiration and revive the patient.

There are several methods that have been suggested and used for inducing artificial breathing, but to save delay in selecting one the layman should have explained to him in a book of this kind one method only, and that one the method that has been accepted as the best, namely, the Schafer method (see Fig. 105).

Schafer's description of this method, as quoted by Crile, is as follows, except that the technical words and expressions have been eliminated and ordinary ones that will be understood by a layman substituted:

The subject, whether a drowned person or not, is allowed to lie prone, *i.e.*, face downward, no preliminary manipulation of the tongue being required. The operator kneels or squats either across or on one side of the subject, facing the head, and places his hands close together flat upon the back of the subject over the loins, the fingers extending over the lowest ribs. By now leaning forward upon the hands, keeping the elbows extended, the weight of the operator's body is brought to bear upon the subject, and this not only compresses the lower part of the chest but also the belly upon the ground, the pressure being fairly equally distributed. The result of this is that not only is the chest diminished in extent from before back, but, owing to the pressure which is communicated to the belly, the belly contents are compressed and tend to force the muscle partition between the chest and belly up, so that the chest is diminished in capacity

from above down. This is no doubt the reason why the pressure method when applied with the subject lying on his belly is more effective than when applied, as by Howard, with the subject lying on his back. The pressure is applied not violently but gradually during about three seconds, and is

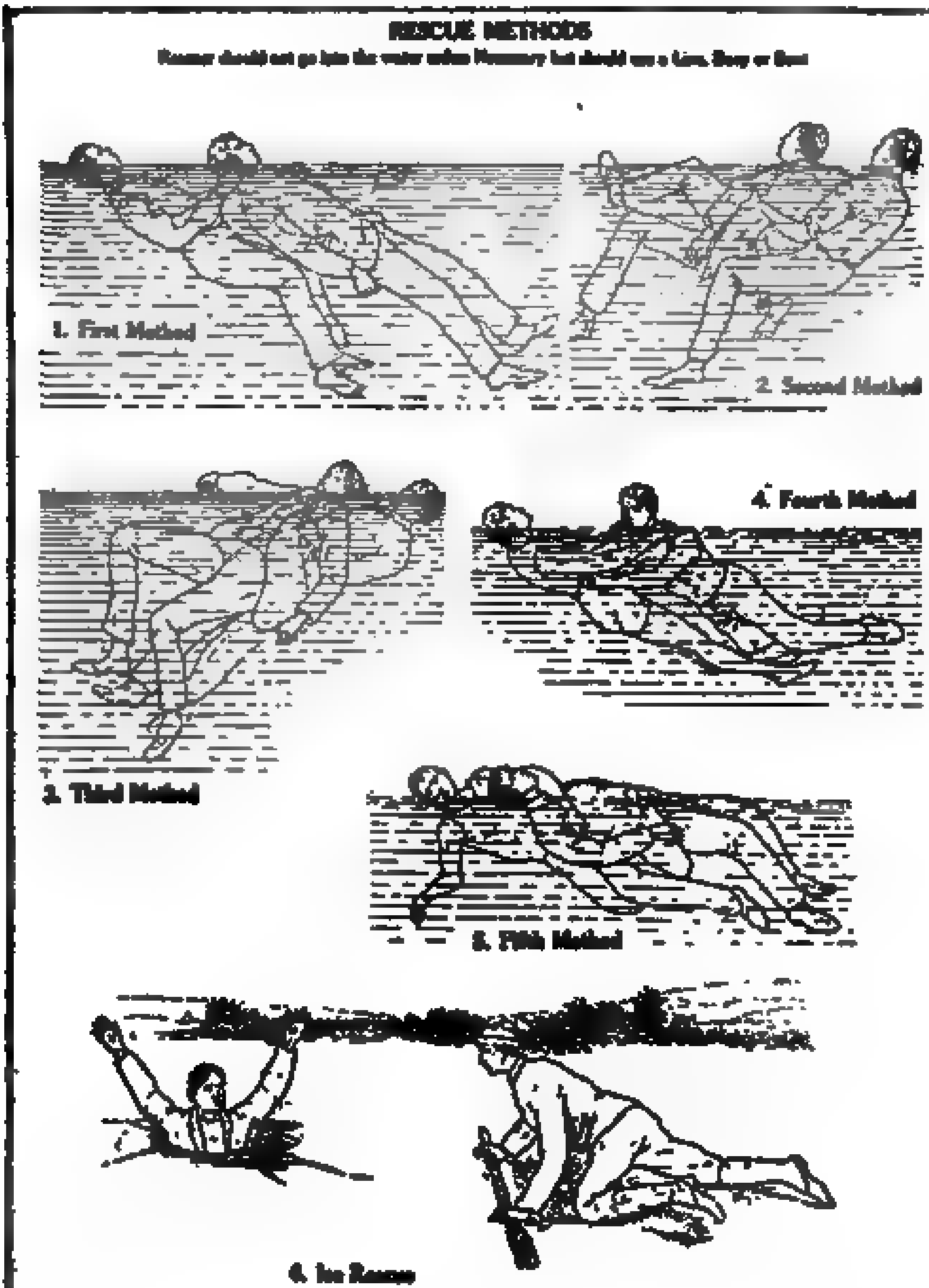


FIG. 104A

then released by the operator swinging his body back, but without removing his hands. The elasticity of the chest and belly causes these to resume their original dimensions and air passes in through the windpipe. After two seconds the process is again commenced, and is continued in the same

way, the operator swinging his body forward and backward once every five seconds, or about twelve times a minute, without any violent effort and with the least possible exertion. This last condition, viz., the absence of muscular exertion, other than that involved in swinging forward and back-

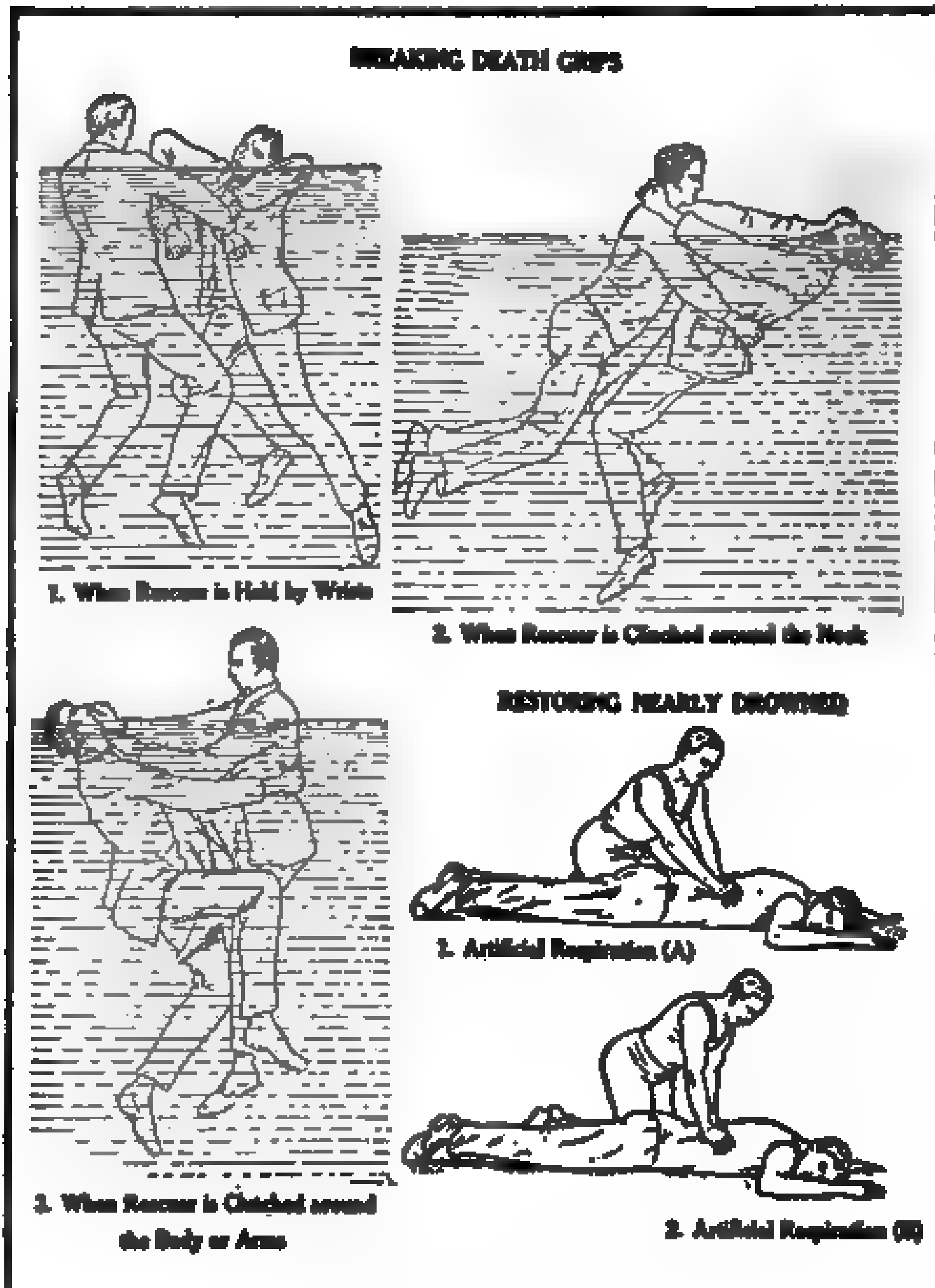


FIG. 105.

ward, renders it possible to continue the process without fatigue for an indefinite time. It can further be carried out unaided by a woman almost as well as a man, by children upon children; it hardly requires to be taught, a simple demonstration sufficiently teaches it to a large audience. Its

advantages in drowning cases over any other method which involves the position on the back are sufficiently obvious, for with it there is no risk of obstruction by water or slime or the contents of the stomach, which can not accumulate in the throat, but must come away by the mouth, and the tongue, in place of falling back, as in the position on the back, falls forward and is unable to produce obstruction.

Crile says in regard to this method: "Schafer's method should be used in all cases in the absence of medical assistance or outside of a hospital, and even in a hospital in the absence of immediate surgical aid." He further says: "Simple artificial respiration is the only hope in drowning and other accidents occurring when professional help is not at hand." When the patient is able to swallow, a small cup of black coffee, or hot milk may be given, and repeated a few times at intervals of an hour. If he does not swallow well, and an ordinary syringe is available, the coffee may be injected into the bowel and left there, but the effect is slower.

It is scarcely necessary to state that the patient should be removed to a warm place, the wet clothing removed, and the lower parts of the body covered and artificially warmed. Pending the arrival of the doctor the patient should be closely watched, and if signs of collapse appear, renewed efforts should be made. Prolonged and systematic rubbing of the skin and kneading of the muscles will assist in promoting the circulation of the blood.

RESUSCITATION FROM ELECTRICAL SHOCK[1]

An accidental electric shock usually does not kill at once, but may only stun the victim and for a while stop his breathing.

The shock is not likely to be immediately fatal because (*a*) The conductors may make only a brief and imperfect contact with the body. (*b*) The skin, unless it is wet, offers high resistance to the current.

Hope of restoring the victim lies in prompt and continued use of artificial respiration. The reasons for this statement are: (*a*) The fact continuously depends on an exchange of air, as shown by the fact that we must breathe in and out about 18 times a minute. (*b*) If the body is not thus repeatedly supplied with air, suffocation occurs. (*c*) Persons whose breathing has been stopped by electric shock have been restored after artificial respiration has been continued for approximately two hours.

INSTRUCTIONS.—Follow these instructions even if the victim appears dead.

I. Break the circuit immediately.

1. With a single quick motion separate the victim from the live conductor. In so doing avoid receiving a shock yourself. Many have, by their carelessness, received injury in trying to disconnect victims of shock from live conductors.

Observe the following precautions: (*a*) Use a dry coat, a dry rope, a dry stick or board, or any other dry nonconductor to move either the victim or the wire, so as to break the electrical contact. Beware of using metal or any moist material. The victim's loose clothing, if dry, may be used to pull him away; do not touch the soles or heels of his shoes while he remains in contact, the nails are dangerous. (*b*) If the body must be touched by your hands, be sure to cover them with rubber gloves, mackintosh, rubber sheeting, or dry cloth; or stand on a dry board or some other dry insulating surface. If possible, use only one hand. If the victim is conducting the current to ground, and is convulsively clutching the live conductor, it may be easier to shut off the current by lifting him than by leaving him on the ground and trying to break his grasp.

2. Open the nearest switch, if that is the quickest way to break the circuit.

3. If necessary to cut a live wire use an ax or a hatchet with a dry wooden handle, or properly insulated pliers.

II. Attend instantly to the victim's breathing. Use the Schafer method of artificial respiration as described under treatment of the apparently drowned (page 477). Burns of the skin should be treated as described for ordinary burns. Warmth to the body, gentle rubbing, and later hot water, milk, or coffee if the subject can swallow, are indicated, but do not give any liquids whatever by mouth until the subject is fully conscious.

[1] Taken from "Rules for resuscitation from electric shock." Issued by the National Electric Light Association.

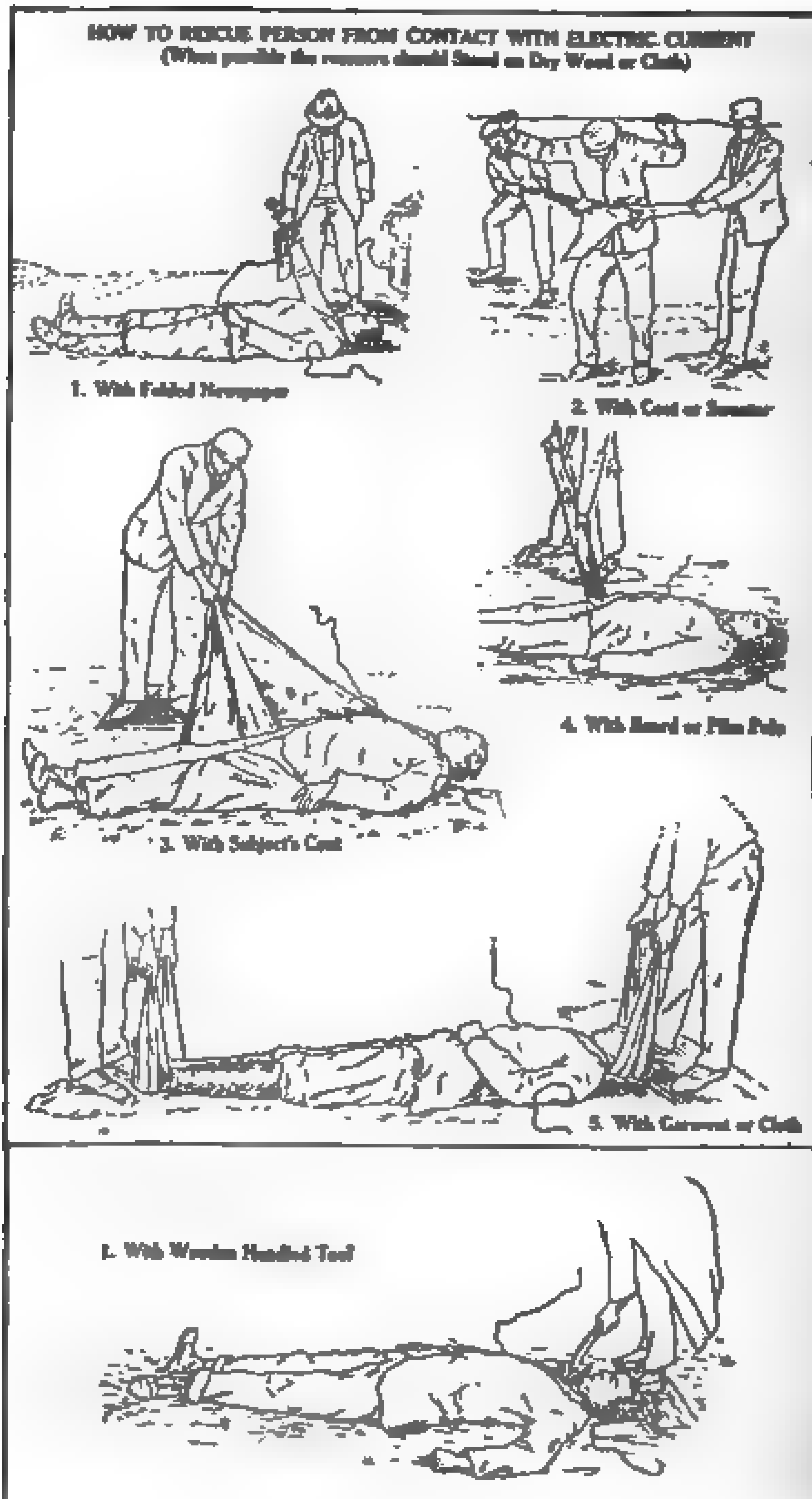

HOW TO RESCUE PERSON FROM CONTACT WITH ELECTRIC CURRENT
1. With Folded Newspaper
2. With Coat or Sweater
3. With Subject's Coat
4. With Board or Pike Pole
5. With Garment or Cloth
With Wooden Handled Tool

FIG. 106.

DIRECTIONS TO BE FOLLOWED IN CASE OF POISONING
(Health Bulletin No. 17)

Send for the doctor immediately, if practicable, and if the nature of the poison is known, have the messenger inform the doctor so that he may come prepared. If the poison is unknown, but the bottle from which it was taken is found, save the bottle as it may help in case of legal investigation. If the poison has been taken with suicidal intent and the patient survives, the same caution is applicable that was mentioned under drowning, gas poisoning, etc. Warmth to the body, light stimulation, and encouragement are indicated.

In treating cases of poisoning first give an antidote, if one is available; second, promote early and repeated vomiting to remove the bulk of the poison; third, give something that will help envelope the poison left in the stomach and prevent its further absorption into the system; fourth, remedy the damage that has been done, so far as this is possible.

The following "general antidote," which should be prepared as needed, should be given when poisoning by any of the poisons mentioned in this book occurs or if the poison is unknown: Magnesia, 2 teaspoonfuls; charcoal, 2 teaspoonfuls; tannic acid, 1 teaspoonful. These dry powders should be kept thoroughly mixed in the above proportions in an air tight bottle and when needed one heaping tablespoonful should be mixed with a cupful of water. This is one adult dose and should be repeated.

Should there be no tannic acid on hand, a cupful of very strong tea or tea of oak bark will take the place of the tannic acid and water.

Vomiting or puking may be induced by tickling the throat with a feather or pushing the finger down the throat, or by the administration of one of the following emetics by mouth:

Mustard.—One tablespoonful stirred to a cream with a cupful of tepid water.

Common Salt.—One tablespoonful to a cupful of tepid water. Not very certain as an emetic.

Alum.—Two teaspoonfuls to a cupful of tepid water This is a rather feeble emetic.

Ipecac.—Give 1 tablespoonful of the sirup in a cupful of tepid water. Repeat once if necessary.

The doses recommended throughout this article are for adults; the amount should be proportionately small for children (see p. 452).

Unknown Poison

Give "general antidote" following by emetics or raw whites of several eggs; or, in their absence, milk, or flour and water. The white of egg, particularly, is inclined to pick up part of the poison left in the stomach and hold it until the patient can be made to vomit again. If the body is limp and respiration is feeble, tea or coffee can be given as a stimulant, and warmth applied to the body with massage or rubbing will tend to support the circulation.

OPIUM, LAUDANUM, PAREGORIC, MORPHINE, CODEINE, HEROIN, INDIAN HEMP

Give the "general antidote," or potassium permanganate (one-third teaspoonful dissolved in a pint of water, no undissolved crystals should remain in the fluid), or peroxide of hydrogen (2 teaspoonfuls in a pint of water), or borax, or baking soda (about 1 tablespoonful to the pint of water) followed by an emetic. Whites of eggs and considerable quantities of strong tea or strong black coffee should be given, or if unable to swallow, inject the coffee into the bowel with a syringe.

Give sweet spirits of niter (1 teaspoonful in water three times a day) to aid excretion by kidneys.

Keep patient awake by shaking, striking with wet towel, applying cold water over face and chest, or forced walking.

Wines and liquors must not be given.

When respiration becomes slow and irregular, artificial respiration should be employed, the same as is used to restore the partially drowned.

After the dangerous symptoms have subsided, the patient should be put in bed, warmth applied, and he should be carefully watched for some time.

ARSENIC, RATSBANE, PARIS GREEN, "ROUGH ON RATS," FOWLER'S SOLUTION

The best antidote, if the ingredients can be obtained, is prepared by mixing a teaspoonful of magnesia with a cup of water, adding 2 tablespoonfuls of tincture of iron, stirring well, and giving the whole in one dose; or the "general antidote" may be given, followed by emetics, raw whites of eggs mixed with water, or large drinks of hot greasy water, or salt and water (tablespoonful to pint), or strong tea. Magnesia may be given in tablespoonful doses mixed with water. Lime water in large quantities is of some value, and in its absence lime which may be scraped from the walls or ceiling and mixed with water may be administered.

Protect stomach with 2 tablespoonfuls of sweet oil, gruel, starch, mucilage, flaxseed tea, or elm-bark tea. Castor oil (2 tablespoonfuls) should be given after vomiting occurs even though the bowel movements are frequent.

Pain can possibly be lessened by hot bottles to the stomach and bowels.

Keep patient warm with artificial heat or extra garments, and give strong coffee to avert collapse.

STRYCHNINE, NUX VOMICA (DOG BUTTON), FISH BERRIES, IGNATIA BEAN

Give "general antidote" or charcoal (1 tablespoonful) or strong tea followed by an emetic, then 15-grain doses of bromide of soda or potash in water repeated every hour until three or four doses have been taken. Several whiffs of ether may be inhaled from a handkerchief at the beginning of a spasm.

Give sweet spirits of niter (1 teaspoonful in water three times a day).

Follow by a purge of Epsom salt or any other saline cathartic that is at hand.

Artificial respiration should be employed the same as is used to restore the partially drowned (page 476). Remove the patient to a darkened room and keep as quiet as possible; avoid any sudden noises.

BICHLORIDE OF MERCURY (CORROSIVE SUBLIMATE)

Promote vomiting, if not already present, by giving mustard in water. Do not use salt as an emetic.

Give raw whites of eggs in water or milk or give milk or mucilage in abundance. In absence of eggs, chop up raw, lean meat finely and diffuse through water or milk and give. It is necessary that vomiting be induced after the eggs, milk, or meat are given, as the mixture formed of these substances will be absorbed if allowed to remain.

The "general antidote," strong tea, and later flour and water, barley water, or flaxseed tea, or elm-bark tea may be given.

Borax in water, about a tablespoonful to the pint of water, is recommended, but is of doubtful value.

Stimulate with strong coffee if necessary.

ACID POISON-ACETIC, MURIATIC, NITRIC, SULPHURIC, ETC.

Give no emetic.

Give "general antidote," large drinks of water (or milk) with chalk, whiting, borax, magnesia, or baking soda, or wood ashes, or strong soapsuds; plaster from the wall may be given in emergency; olive oil, raw whites of eggs beaten up with water, and later flaxseed tea, elm-bark tea, gruel, starch, mucilage freely.

Laudanum (20 drops) may be given if there is much pain.

CARBOLIC ACID AND CRESOL AND COAL-TAR DISINFECTANTS GENERALLY

Give alcoholic liquors (whisky, brandy, etc.) or equal parts of alcohol and water freely to dissolve the poison. Produce vomiting to get rid of the alcoholic mixture. In the absence of alcoholic liquors, give vinegar, soapsuds, or raw whites of eggs in water. Give solution of Epsom or Glauber salt or sodium phosphate well diluted to hasten elimination of acid that may have entered the circulation.

Do not give oils or glycerin.

Milk, gruel, flaxseed tea, or elm-bark tea may then be given. Hot applications to extremities. For collapse give strong coffee. Apply artificial respiration if breathing stops.

ALKALI POISONS-LYE, HARTSHORN, PEARLASH, ETC.

Assist vomiting with large drinks of tepid water.

Give vinegar, lemon juice or orange juice, hard cider, whites of eggs beaten with water.

Follow by sweet oil, milk, gruel, barley water, flaxseed tea, or elm-bark tea

PTOMAINE POISONING FROM FISH

The symptoms of ptomaine poisoning are practically the same as those of "Cholera Morbus."

"General antidote," emetics, copious drinks of strong tea, repeat emetic, then castor oil (2 tablespoonfuls) should be given. Continue treatment as given for cholera morbus.

CHOLERA MORBUS (SPORADIC CHOLERA)

Cholera morbus is an affection of the stomach and intestines, attended by vomiting, purging, and cramps. It comes on suddenly, and may begin by vomiting or purging. It is usually met with during the hot months of summer. It is frequently caused by eating unripe and indigestible fruits and vegetables, decomposed or improperly cooked fish, shellfish, or salad mixtures. Drinking large quantities of iced water and sudden checking of the perspiration, or irritants of any kind, may set up the trouble. The disease usually begins suddenly, often at night, with vomiting, after a feeling of uneasiness, nausea, or a severe cramp. The contents of the stomach are first thrown up, then a bilious matter. The stools are at first solid or semisolid, but they soon become more watery, lose their color, and sometimes appear not unlike the rice-water stools of genuine Asiatic cholera. The patient soon has a wasted look. His thirst is unquenchable. His skin may become cold and clammy and the pulse very weak. Cramps may occur in the feet and in the calves of the legs. The disease runs a rapid course. The acute symptoms may subside in a few hours. The attack seldom lasts more than 12 hours. Recovery is the rule, but treatment should be promptly applied.

Treatment.—Apply a large mustard plaster to the abdomen. Give 15 drops of laudanum. If the dose is rejected (immediately vomited), try it again. If it is still not retained, then try 2 tablets of Sun Cholera Mixture. If vomiting quickly occurs, then inject into the rectum by means of a glass or rubber syringe about 20 drops of laudanum mixed with a little thin starch or a little water. The rectal injection should be given immediately after an evacuation, and the patient should be instructed to hold it as long as possible. In whatever way the remedy is given, the dose should be repeated in about one hour if the vomiting and purging continue.

If must not be forgotten, however, that all these remedies contain opium, and that if the patient is inclined to sleep or shows other constitutional effect of the drug the dose must not be repeated.

The nausea and thirst may be controlled by cracked ice placed in the mouth. Small quantities of carbonated water may be allowed. If the thirst is very urgent a tablespoonful of iced water may be given at short intervals.

BROKEN BONES (FRACTURES)

There are many varieties of fracture. A fracture is said to be simple where there is no open wound directly over the bone injury; compound when there is an opening in the skin and soft parts extending down to the broken bone; comminuted when the bone is broken in several places; complicated when it is associated with other injuries, as dislocation of the joint or rupture of the main artery of the limb; impacted when one fragment is driven into another.

SIMPLE FRACTURES

In a typical, well-marked fracture of a bone in one of the limbs we will find the following:

1. History of an injury.
2. Pain and tenderness, and later swelling; and sometimes discoloration of the part.
3. Deformity in some cases.
4. Shortening, due to the fact that in most cases the break is obliquely across the bone and the fragments override.
5. Scraping noise, called crepitus, when the ends of the bones are rubbed together.
6. Inability or disinclination to use the part.

Any of these signs may be absent in a given case. Sometimes it is impossible to tell without an x-ray examination whether one has to deal with a fracture, a sprain, or a bruise, but in such cases it is always best to assume that there is a fracture.

In transverse fracture, where the break is straight across the bone at a right angle with the long axis of the bone, or in a fracture near a joint, there may be no shortening and no deformity. In fractures of certain bones, as the skull or the spine, or in an impacted fracture, there may be no motion. In fracture of the kneepan or the elbow the fragments are pulled apart by the muscles, so that there is lengthening instead of shortening.

Examination should always be made as soon as possible after the accident. Under the most favorable circumstances it is sometimes difficult to determine whether a bone is broken or not, and the difficulty is greatly increased if the examination is delayed until inflammatory swelling has set in. In fractures of the extremities the sound limb should always be placed alongside the injured one for comparison. The shortening in fracture of the thigh may be from 1 to 3 inches, but it must not be forgotten that in some persons there is a natural difference of as much as half an inch in length of the pair of legs; and a limb may be otherwise naturally deformed and this deformity should not be mistaken for accidental deformity. In the leg below the knee there are two parallel bones (tibia and fibula). In simple fracture affecting only one of these bones the deformity and crepitus are less marked; and the same may be said of the forearm, if fracture exists in only one of the bones (radius or ulna). If both bones of the leg (tibia and fibula) or of the arm (radius and ulna) are affected, there may be considerable deformity, and it is a curious fact that fracture of these bones seldom occurs on the same level. The distance between the fractures may be from 1 to 3 inches, usually greater in the leg than in the forearm.

Crepitus (the sound heard or feeling imparted to the hand when the broken ends of the bone are rubbed together) is a valuable symptom of fracture, but it can not always be detected, and when other marked signs or symptoms are present, need not and should not be looked for. In fractures of the leg below the knee or the forearm, involving only one of the bones, it is hard to make out because of the difficulty of rubbing the broken ends together, and when much swelling exists the difficulty is increased, or a false crepitus may be produced. In impacted fractures, which occur chiefly in the neck of the thigh bone, no effort should be made to obtain crepitus. The important thing in such cases is not to disturb the impacted fragments, for if pulled apart recovery is rendered more difficult.

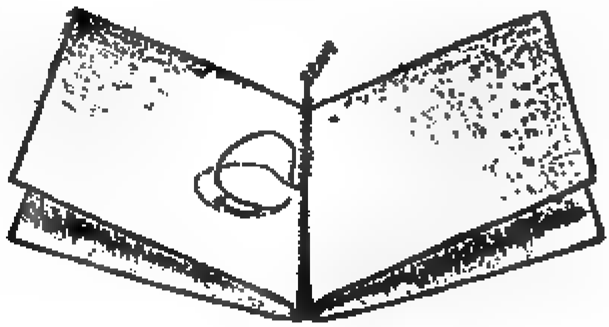
Treatment.—This can best be described by taking as an example a fracture of both bones in the middle of the leg. The object of the treatment is to

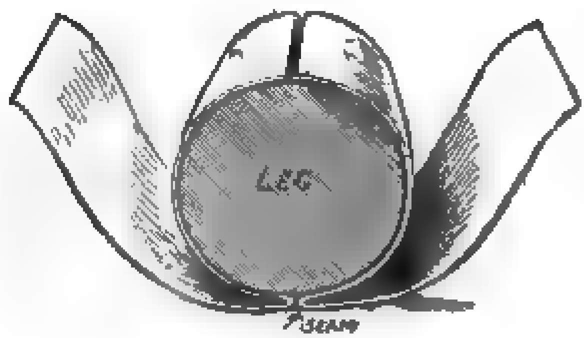
1. Set the bone (known as reducing the fracture).
2. Apply some dressing that will hold the broken pieces of bone in position.
3. Watch for swelling, and see that the bandages are not too tight.

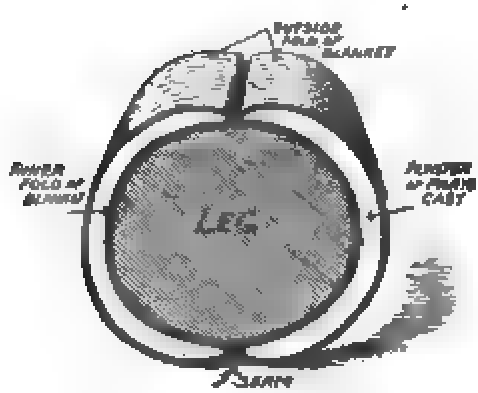
In handling a broken leg, or one in which a broken bone is suspected, the leg should always be stretched by grasping it above and below the fracture point. This prevents deformity, injury to the blood-vessels, nerves, and soft parts of the sharp ends of the bones, and causes the patient less pain. If a patient with a broken leg is to be placed on a bed, one or two boards should be passed under the springs of the bed from side to side to prevent sagging, as this would cause displacement of the bones and pain to the patient. One person grasps the foot firmly, with both hands placed over the instep and heel, respectively, and pulls down, while another person grasps the thigh just above the knee with both hands and pulls in the opposite direction. While the leg is thus extended and the attention of the two assistants is directed solely to this injured leg, other persons pick up the patient carefully and transfer him to the bed. If a doctor can be reached in a comparatively short time, the leg can be held in position by means of

sandbags. The two legs of a pair of overhauls cut off, filled with sand or heavy earth, and tied at the ends, when placed along either side of the leg will answer the purpose. The broken leg is approximately in proper position when the ball of the great toe, the inner ankle, and the inside of the knee are in the same vertical plane; in other words, if a board were placed on edge along the inside of the leg, the three points mentioned would all touch the board.

If the patient is to be transported to the doctor, or if some time will elapse before the doctor can arrive, the leg must be incased in some dressing that







will hold it stiff and not allow the broken bones to move. Any dressing applied for this purpose should be well padded with cotton, soft underclothing, moss, or anything that is available. Particular attention should be paid to the ankle, the heel, and also the parts near the break to see that they are all well cushioned. A piece of heavy pasteboard moistened can be molded fairly well to the leg. Sometimes a pillow, particularly a hair pillow, if supported by strips of wood on the outside to prevent it bending, can be used. The dressing is bound to the limb with bandages. These may be made by tearing up a sheet, pillowcase, shirt, or blanket.

The toes should not be inclosed in the dressing, because if the doctor can not be reached in a short time, it is necessary to watch the toes to determine whether the swelling has made the dressing too tight. If the toes are bluish and cold, the bandages should be loosened to let the blood circulate. If plaster-of-Paris or cement is at hand, a Bavarian splint can be made by a layman. Take two pieces of blanket as long as the lower leg and 18 inches wide. Fold each piece in the center along its long dimension and sew these folds together, as shown in the illustration. Place the leg on the seam, bring the upper fold up on either side, and let the two surround the leg, trimming off the blanket so that the edges simply come together but do not lap. Now smear the wet plaster-of-Paris or cement over this layer, and then bring up the other layer around the leg, trim it in the same manner, and tie the dressing on with several bandages until it "sets." This kind of a splint can be opened at any time for examination of the leg, the seam at the back acting like the hinge of a clam shell. Possibly wet clay could be used in such a dressing if the limb could be placed before a fire to dry.

The necessary thing in all first-aid work is to get the principles firmly fixed in the mind, and human ingenuity will find a way of carrying out these principles. A box can be constructed to incase the limb, it being properly padded. Whatever dressing is applied, if the patient is to be moved any distance, it is best to make the dressing long enough to cover the joints above and below the fracture and thus prevent the bones moving, as there will then be less danger of displacing them and the patient will be more comfortable. If the bandage is rolled loosely and stirred about in a vessel of thick starch it can then be applied hot, and when dry, forms an excellent stiff dressing; but such a bandage should not be stretched while being applied, because the starch contracts in drying and the dressing would in that case be too tight. A starch dressing after drying can be split up along the front leg to loosen it, and then held in position by several bandages.

COMPOUND FRACTURES

Compound fractures are serious accidents and require prompt attention The treatment, so far as the bone is concerned (place it in normal position and keep it there), is the same as for simple fracture. But to do this and at the same time give proper attention to the wound in the soft parts (the open wound extending down to the bone) frequently demands the highest surgical skill.

Shock from loss of blood is the immediate danger. Inflammation, erysipelas, blood poisoning, or lockjaw may set in later, and still later the patient may become exhausted from long continued suppuration.

Treatment.—If the wound is very small, it should be well cleaned with hot water (water that has been raised to the boiling point and allowed to cool down to about 120° F.) or by antiseptic solution (solution bichloride of mercury 1 to 5000) (see page 473) then covered with aseptic gauze, and the case treated as a simple fracture. (Clean hands as indicated on page 473). The services of a physician should be obtained if possible as the patient should have an injection of serum (tetanus antitoxin) to prevent lockjaw.

In nearly all cases, however, the safest and best plan is to leave the wound uncovered by splint or bandage, so that light dressings may be easily applied and frequently changed. The wound should be thoroughly cleansed with hot water and antiseptic solution before reducing the fracture, for if dirt on the end of the bone or skin is drawn into the wound when the bone is returned to its proper place, infection with organisms causing lockjaw or other dangerous conditions may occur, by which the patient may lose his limb or his life. The splints or extending apparatus should be so arranged that the wound is freely accessible and easily drained. Strips of aseptic gauze should be placed in the wound and gently carried down to the bottom by means of a probe, and a larger piece of aseptic gauze, in loose folds should be laid over the wound.

The aseptic gauze dressing should be renewed every day or every second day, or as often as necessary to keep the wound well drained until it heals from the bottom.

In severe cases amputation may be necessary to save life, and in all cases the patient should be placed under the care of a surgeon as soon as possible.

FRACTURE OF THE LOWER JAW

Fracture of the lower jaw may be simple, compound, or comminuted. The mucous membrane of the mouth is nearly always lacerated, the bleeding is usually not severe (oozing only), but there may be hemorrhage from an artery (the inferior dental), saliva dribbles from the half open mouth, the teeth may be out of line, pain is apt to be severe, and there may be considerable deformity and a false point of motion.

Treatment.—Restore the parts to the natural position and keep them at perfect rest, first washing out the mouth with hot water to cleanse it and check bleeding. If the bleeding is very severe, pressure should be made by the thumb or finger for a time on the bleeding point, if possible, or on the large artery (carotid) on the side of the neck, which may be easily located by the pulsation. Loose teeth or pieces of bone should not as a rule be removed. Mold them into place, bring the teeth and jaw into natural lines, and keep them so by a pasteboard or binder's board splint, held in place by a four-tailed bandage.

If the parts can not be kept in place by the methods described, the teeth may be fastened together with wire passed between the teeth on each side of the break and twisting the ends together. Feed the patient on liquid food through a rubber tube introduced behind the last tooth or through any space left by the loss of a tooth, the object being to prevent movement of the jaw. Wash out the mouth frequently with hot water, and, if necessary, change the dressing every two or three days until the end of about the sixth or eighth week, when, if all goes well, union will be complete, and the splint and bandage may be discontinued.

FRACTURE OF THE NOSE

If the nose is broken and it is possible to reach a doctor within four or five days, it is best for the layman not to attempt to restore the bones to position. If, however, there is great depression of the nose, and a doctor's services can not be obtained for a long time, a gentle effort may be made to lift the bones into position by passing into the nostrils a thin stiff piece of metal well wrapped with some soft material. When the patient can breathe well through either nostril while the other nostril is held closed, it is an indication that the bones are in fairly good position. The operation described is a technical procedure and should not be attempted by a layman except in an extreme case where medical assistance can not be obtained.

FRACTURE OF THE SKULL

If the skull is fractured, there may be unconsciousness, paralysis, bleeding from the nose or ears, or other unusual manifestations. It is important to get the doctor as soon as possible. In the meantime, it is a very good general rule in this, as well as in all first-aid work, to keep the patient's head cool and the feet warm. If ice is at hand, an ice cap can be made by tying up the broken ice in a piece of mackintosh, oilcloth, rubber sheeting, or other waterproof material that will keep the patient from getting wet. Warmth to the feet and body can be applied by hot water in bottles or jugs, or by heating plates, stones, or bricks in water and wrapping them well. Remember always that an unconscious man or one seriously injured cannot tell his willing helpers when a thing is too hot, and due care should be exercised. Do not pour whisky down the patient's throat. If he is able to swallow, he probably does not need a stimulant; and if he can not swallow, the whisky will choke him. In many cases, the first resort of the layman is the whisky bottle, and when the doctor arrives he can not tell how much of the stupor is due to the whisky and how much to the injury.

If it is impossible to obtain the services of a physician for several days, care should be taken to see that the patient passes his urine. If no urine is voided for 24 hours after the injury a hot pack of towels, wrung out of hot water, should be placed over the bladder; the pack must not be too hot or the patient may be burnt. If this does not have the desired effect, a soft rubber catheter, if one is obtainable, after being boiled for five minutes, should be carefully introduced into the urinary canal and the urine drawn off. Before taking this step the person who has charge of the patient should thoroughly cleanse his own hands and carefully wash the genital organs of the patient with soap and water.

FRACTURE OF RIBS

Fractures of the ribs are sometimes difficult to determine, but if present there will usually be a stitchlike pain upon taking a deep breath; and if the chest is quickly compressed by one hand on the breastbone and the other on the backbone the patient may complain of pain at the point where the bone is broken, usually somewhere under the armpit. As splints can not be applied to a part like this, and as the ribs are constantly moving in breathing, the best that can be done in the way of first aid is to strap the injured side with strips of sticking plaster 2 or 3 inches wide, long enough to reach from the middle line in front or a little beyond to the middle line behind or farther, the strips lapping over one another, drawn rather tightly and extending from the lowest ribs well up into the armpit. In the absence of sticking plaster a strip of muslin 12 inches wide, passed around the chest rather tightly several times and snugly pinned, will give some comfort until the doctor arrives.

FRACTURE OF THE THUMB AND FINGERS

Treatment.—Put the fragments in place by extension and pressure; then cut a piece of pasteboard, leather, cigar box, or thin board long enough to extend from above the wrist joint to a little below the ends of the fingers and a little wider than the hand. Cover the board with lint or any soft cloth, place the palm of the hand flat upon it, and apply a bandage around the whole hand and wrist.

If pasteboard or leather be used, it may first be dipped into hot water and then molded to the shape of the thumb or finger and palm of the hand, then lined or covered with cloth and bandaged as above, care being taken not to make the bandage too tight.

FRACTURE OF THE FOREARM

The forearm extends from the wrist to the elbow. When both bones are broken there is apt to be marked displacement and crepitus (grating felt by rubbing the broken ends of the bone together). When only one bone

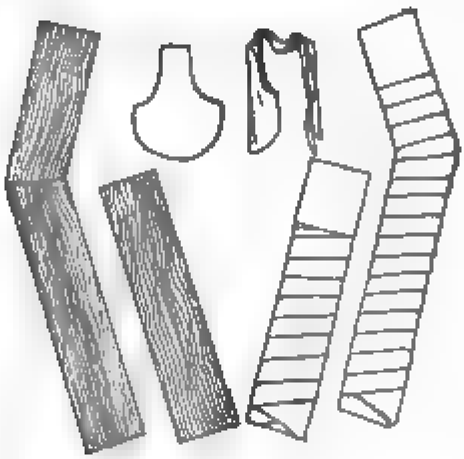


FIG. 107.

is broken, the signs and symptoms are not so clear, but by careful examination the nature of the injury may be determined. When fracture of one of the bones (the radius) occurs near the wrist joint (Colles's fracture) there is generally marked deformity resembling a silver fork in shape.

In fracture of the forearm take a thin board 3½ inches wide and long enough to reach from the elbow to the tips of the fingers (Fig. 107). After stretching the forearm by grasping the hand and the arm above the elbow until it seems fairly straight, lay the palm side of the forearm and hand on the board, well padded, and place on the back of the forearm and hand another similar padded board extending from the elbow to the knuckles. Carefully and evenly bandage the splints, starting at the fingers and working up.

Leave the tips of the fingers uncovered to watch the circulation (Fig. 108). The bandaged arm can be carried in a sling.

Another way to hold the splints in place is to apply strips of adhesive plaster around them, one at the upper and the other at the lower end

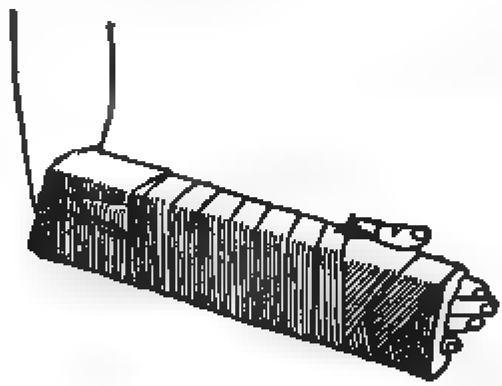


Fig. 108.

If swelling occurs, the bandage must be loosened. The splints should be worn six weeks or two months, but must be removed temporarily every few days, and passive motion, that is, gently bending and straightening of the fingers with the other hand, made to prevent stiffening.

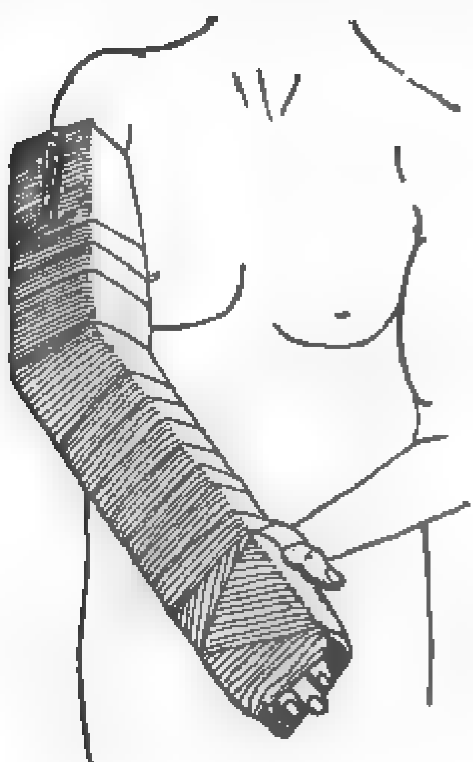


Fig. 109

FRACTURE OF THE ARM (BETWEEN THE ELBOW AND SHOULDER)

Treatment.—In a break of the upper arm it is well to make two gutters of moistened pasteboard, and apply them after padding to the outside and inside of the arm. The entire arm and forearm should then be supported by two angular splints (Figs. 107 and 109) made of this board, one applied

from the fingers to the armpit, the other from the fingers to the shoulder. The padding should be especially heavy and even about the elbow and any other place where the bones naturally come near the skin.

If much swelling occurs, all bandages must be loosened.

The splint should be worn about eight weeks. Under the most favorable circumstances, after fracture, this bone (the humerus) sometimes fails to unite. At least once a week the joints should be moved to prevent stiffness.

Fractures of the arm (of the humerus) at or near the elbow joint or shoulder joint are frequently very difficult to determine, even by the most skillful surgeon, especially if some time has elapsed since the injury was received; and the treatment of necessity is equally difficult.

If near or at the elbow joint, and if there is much pain, heat, and swelling, as is apt to be the case, cold applications should be used, and the arm laid upon a pillow until the swelling has gone down. A rectangular splint of binder's board or leather should then be dipped in hot water and applied to the inner side of the arm and forearm. The splint should be wide enough to extend nearly half-way around the arm. It must be well passed and held in place by a roller bandage, and the forearm supported by a sling.

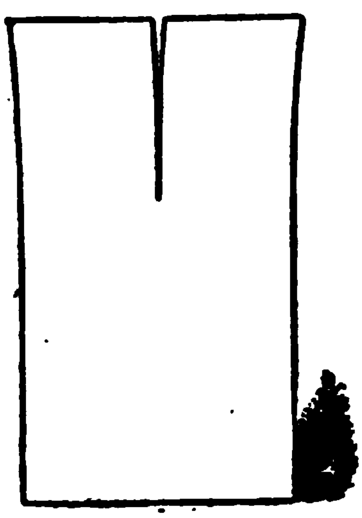


FIG. 110.

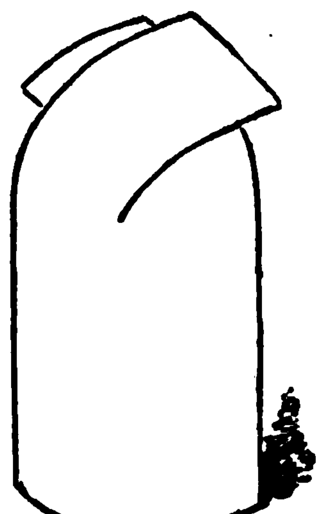


FIG. 111.

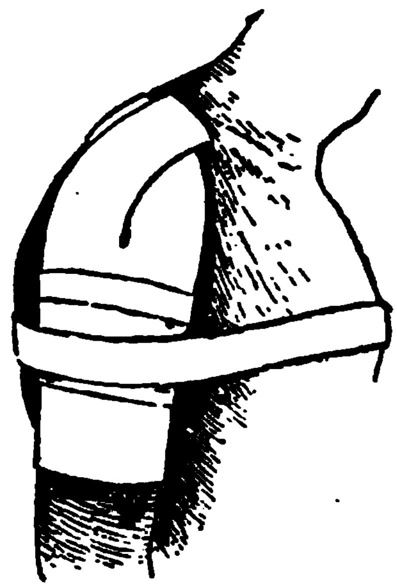


FIG. 112.

If the break is near the shoulder joint, the dressing can be supplemented by slitting a piece of pasteboard, at one end, moistening it, and molding it to form a shoulder cap (Figs. 110, 111 and 112), which is bound in place by passing bandages from the injured shoulder around the body and opposite shoulder.

After the application of any apparatus for fracture of the arm or forearm, the circulation should be carefully watched by feeling the pulse at the wrist. If it can not be felt, or if the fingers swell, the bandages should be removed and reapplied less tightly.

FRACTURE OF COLLAR BONE

The collar bone connects the breastbone to the shoulder. Children may have a greenstick fracture in which this bone is not completely broken across. In adults the fracture is nearly always a simple one, the bones overriding. The shoulder drops downward from its own weight and is drawn inward and forward by the muscles. The first aid indications are therefore to overcome these actions as far as possible, and to force the shoulder upward, outward, and backward. Placing the arm in a sling will draw the shoulder upward to a certain extent, and this can be assisted, if sticking plaster is available, by placing the hand of the injured side on the opposite shoulder and then binding it there by placing the middle of a long strip of 2 or 3 inch sticking plaster under the elbow, one end passing along the forearm to the hand on the shoulder and the other end passing diagonally across the back to meet the first end on the shoulder. Other strips of sticking plaster or a bandage passed around the injured shoulder, then across the back, and fastened around the body, will force the shoulder

backward and to a slight extent outward and make the patient more comfortable until the doctor arrives. In the absence of sticking plaster a bandage applied in a "figure of eight" may hold the shoulders in fairly good position (Figs. 113 and 114). Stand at the patient's back, pass the bandage over one shoulder to the front, then under the armpit to the back, across the back to the front of the opposite shoulder, through this armpit to the starting point on the back. Go over the route several times with some tension on the bandage, and then make the end fast.

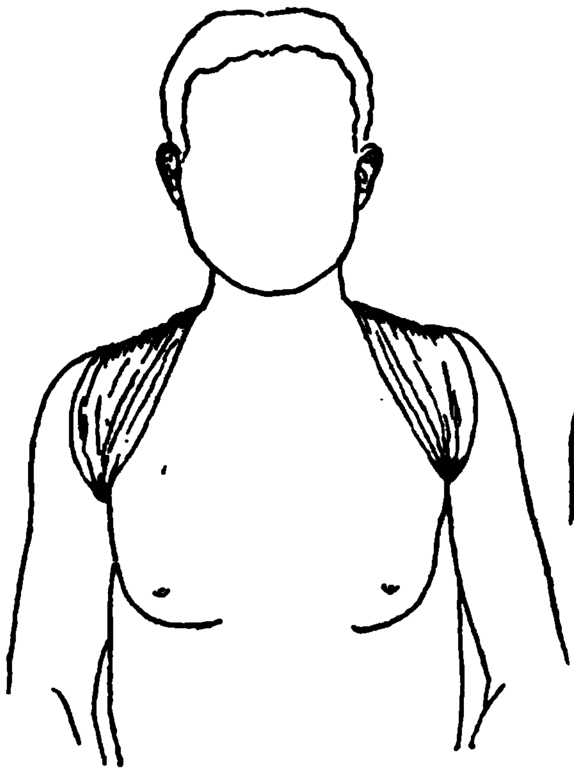


FIG. 113.

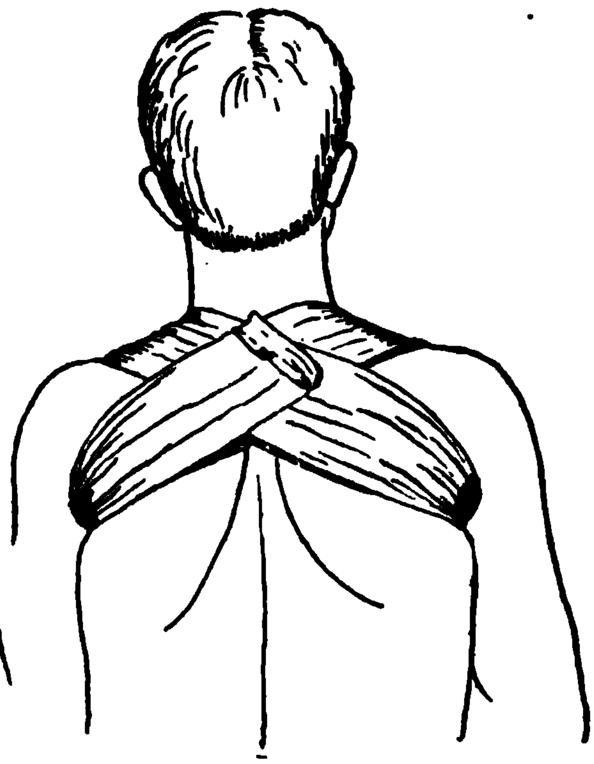


FIG. 114.

FRACTURE OF THE THIGH

The thigh bone (femur) extends from the hip to the knee. Fracturet of this bone may occur in any portion of the shaft, but the most common seat of fracture is about the middle or the middle third. Fractures high up near the hip joint are frequently difficult to make out, and the results of treatment in such cases, even under the care of skillful surgeons, are not always satisfactory.

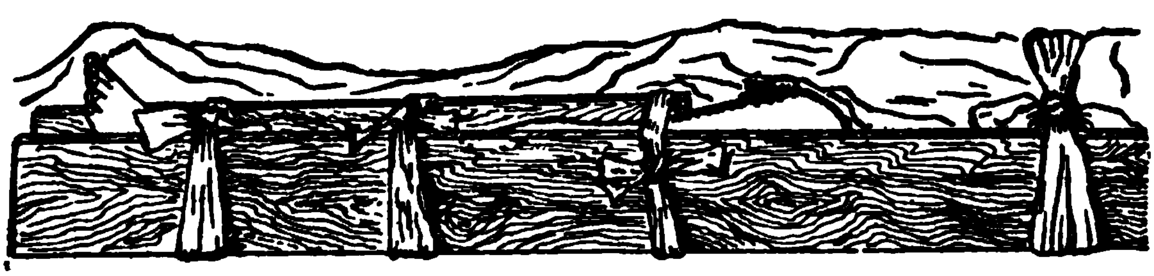


FIG. 115.

In fracture of the middle or middle third of the bone the deformity is usually produced by the lower fragment (the broken end of the lower portion of the bone) being drawn up behind and to the inner side of the upper fragment; the weight of the limb then causes rotation and the foot and toes are turned outward.

If the fracture is a little higher up, displacement is shown by the upper fragment, which, by the action of the muscles, is thrown strongly forward and outward. In either case there are complete loss of power, shortening to the extent of 1 to 2 or 3 inches, pain on the slightest movement, crepitus (grating) if the broken ends of the bone are rubbed together, and abnormal motion.

In impacted fractures, which are met chiefly at or near the hip joint, the shortening may be, and usually is, less marked. Loss of power is usually complete, but not always. Patients have been known to stand and even walk a few steps. Injuries of this kind require the greatest care; the limbs should be handled very carefully. If on slight traction or manipulation crepitus is not felt, no further attempt should be made to obtain this symptom, for in doing so the impacted bones may be pulled apart, which is to be avoided unless especially directed by a skillful surgeon.

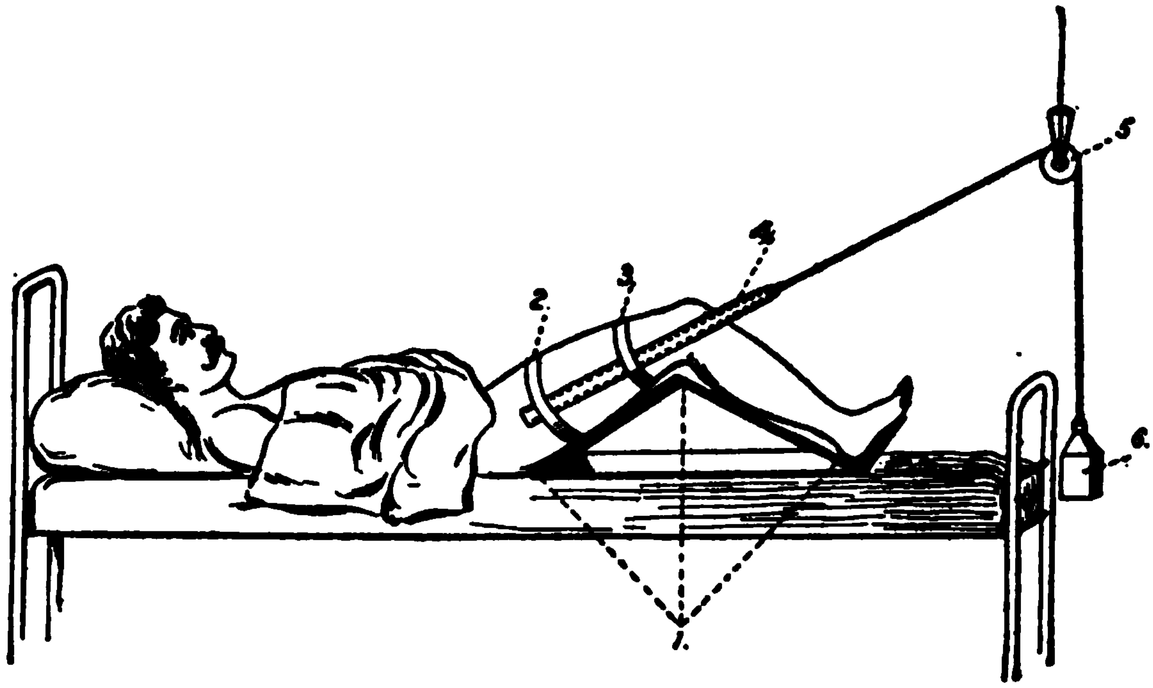


FIG. 116.

Treatment.—In the absence of a physician, about all that can reasonably be done in impacted fracture is to apply a broad bandage around the hips and place the patient in a good bed on a firm mattress and make lateral support by means of boards (Fig. 115) or by sandbags, one on the outside long enough to reach from the upper end of the hip bone to the foot, the other along the inner side of the leg from the crotch to the foot. Fill the bags three-quarters full of dry sand. Keep the leg straight, toes upward.

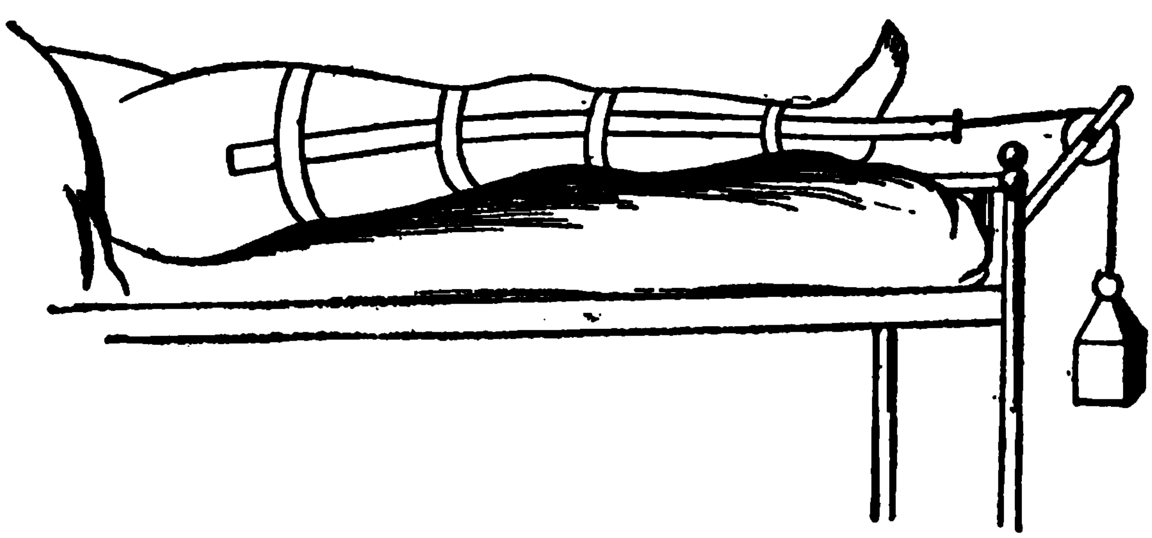


FIG. 117.

Treatment of nonimpacted fracture of the thigh bone at or near the hip joint. Place both legs on the double inclined plane, or make extension and fix this limb in the straight position by means of a long splint (a splint extending from the armpit to the foot), or by the weight and pulley, or by the long splint and the weight and pulley combined in the manner now about to be explained in connection with the treatment of fractures of the shaft of the thigh bone.

Treatment of fractures of the shaft of the thigh bone. In fractures of the shaft of this bone the signs and symptoms, as already stated, are usually well marked. If the fracture is at the upper end or in the upper third of the bone, especially if the upper fragment is tilted forward, the double-inclined plane (Fig. 116) well padded or covered with pillows, with weight and pulley attached by means of adhesive stuck to each side of the thigh as far as the knee, affords the easiest and probably the best means of treatment. But in the majority of cases when the fracture is farther down, about the middle or in the middle third of the bone, the weight and pulley with leg and long splint combined (Fig. 118) are better adapted if properly applied. Sandbags placed alongside may also be used in connection with any of the straight splints. In all cases the fracture should be reduced by gradually pulling

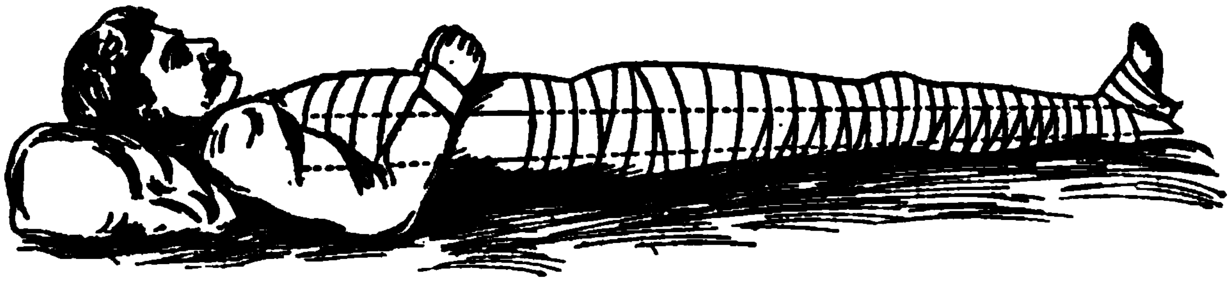


FIG. 118.

and carefully pressing the broken bones into their natural position. In addition to the splints already mentioned, short splints of narrow strips of thin board or binder's board should be applied directly over the seat of fracture. If a double-inclined plane is not at hand, two broad pieces of board may be nailed together at a suitable angle and used instead, always properly padded or covered with pillows.

The Weight and Pulley (Figs. 116 and 118).—The weight and pulley are applied as follows: Measure the distance from 1 inch below the leg and thigh in a straight line (Fig. 117) or the weight and pul-crotch to a point 4 inches below the foot. Cut a strip of adhesive plaster exactly twice as long as the distance just measured and 3 inches wide, and stretch it on a table or on the floor, with the sticky side up. Get a block of wood 4 inches long,

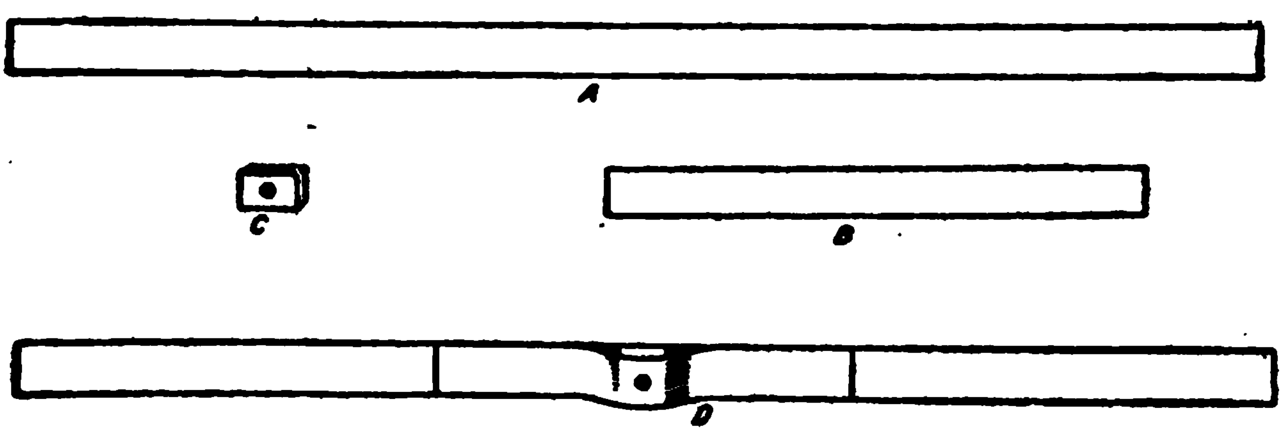


FIG. 119.

about 3 inches wide, and about ½ inch thick, with a hole bored through the center large enough to admit a large cord. Place the block exactly in the center of the long strip of adhesive plaster. Cut another strip of plaster the width of the first and 18 inches long, and place it on the first strip, sticky surfaces together, so as to include the block between the center of each. Thus a stirrup is made, and the long strip of plaster on each side of it applied to the leg and thigh after they have been shaved, extending from a point just above the ankle bone to a point about 1 inch below the crotch on the inner side and to the same level on the outer side, the person applying the plaster being careful to keep the block square when the two ends of the plaster are stuck to the limb. A roller bandage is then applied over the plaster from the ankle up, and a strong cord passed through the

hole in the block and knotted so that it can not slip through. The other end is then passed over a pulley attached to the foot of the bed or elsewhere, as may be convenient, on a line with the extended limb, and a weight of from 5 to 30 pounds, as may be necessary or comfortable to the patient, attached, which may be increased if necessary to overcome muscular spasm. The same kind of apparatus may be used with the double-inclined plane, except that the plaster is applied only to the thigh, the stirrup coming just below the bent knee.

Counterextension may be obtained by raising the foot end of the bed on blocks 4 to 6 inches high. The short splints should be well padded and extend well above and below the fracture, and be held in place by strips of plaster or bandage.

The long splint gives additional support and prevents outward rotation of the leg. It should be well padded, and have a crosspiece at the lower end to keep it in position. Treatment will be required for a period of 8 to 10 weeks, but the extension may be lessened about the end of the sixth week and passive motion made at the knee joint each day, by grasping the leg and gently bending and extending it.

FRACTURE OF THE KNEECAP

Fracture of the kneecap may be transverse, vertical, or oblique. The bone may be broken into two or more irregularly shaped pieces.

Symptoms and Signs.—Loss of power, inability to extend the joint or raise the limb from the bed. In the transverse variety the fragments are widely separated. If seen soon after the accident, the line of fracture, the

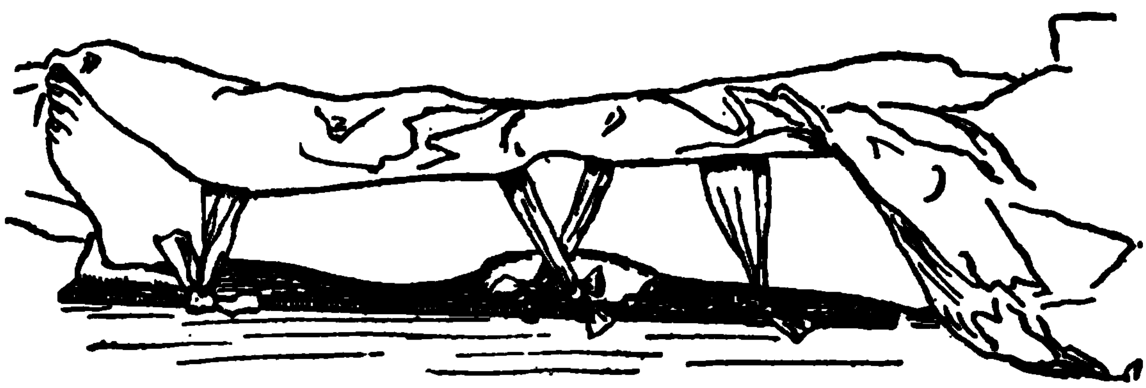


FIG. 120.

gap between the fragments, may be seen and felt. Swelling rapidly appears and the signs are obscured.

Treatment.—Various forms of apparatus are employed, and in hospital practice the injury is frequently treated by surgical operation, with good result. The simplest form of treatment is to place the limb on a long splint with the foot raised so as to relax the thigh muscles, or if the patient is propped up in bed by pillows or a back rest, the limb may be allowed to lie on a level.

This splint should be applied as follows: A padded straight board should be bound on the back of the limb, extending from the heel to the upper part of the thigh. A folded towel placed at the back of the knee, allowing the joint to bend slightly, will be comfortable. One handkerchief, or bandage should be applied below the knee. Another handkerchief should be passed above the kneecap, and be knotted at the back below the knee (Fig. 120). Nails driven into the edge of the board at convenient points assist in holding the bandage in position.

Apply iced water or the ice bag for a few days. If swelling or numbness of the foot is complained of, the bandage is too tight and must be removed.

If the bandages become loose, as they are apt to do every few days, they should be reapplied.

The long splint should be worn about six weeks or two months, when it may be replaced by a shorter molded splint of leather, felt, or pasteboard, to prevent motion at the joint when the patient walks with a cane or crutches. The short splint should be worn for at least a month, and then suitably constructed kneecap should be worn for one year to support the joint. More or less stiffness of the joint is to be expected.

FIG. 121.—Showing appearance of the right foot after Pott's fracture.

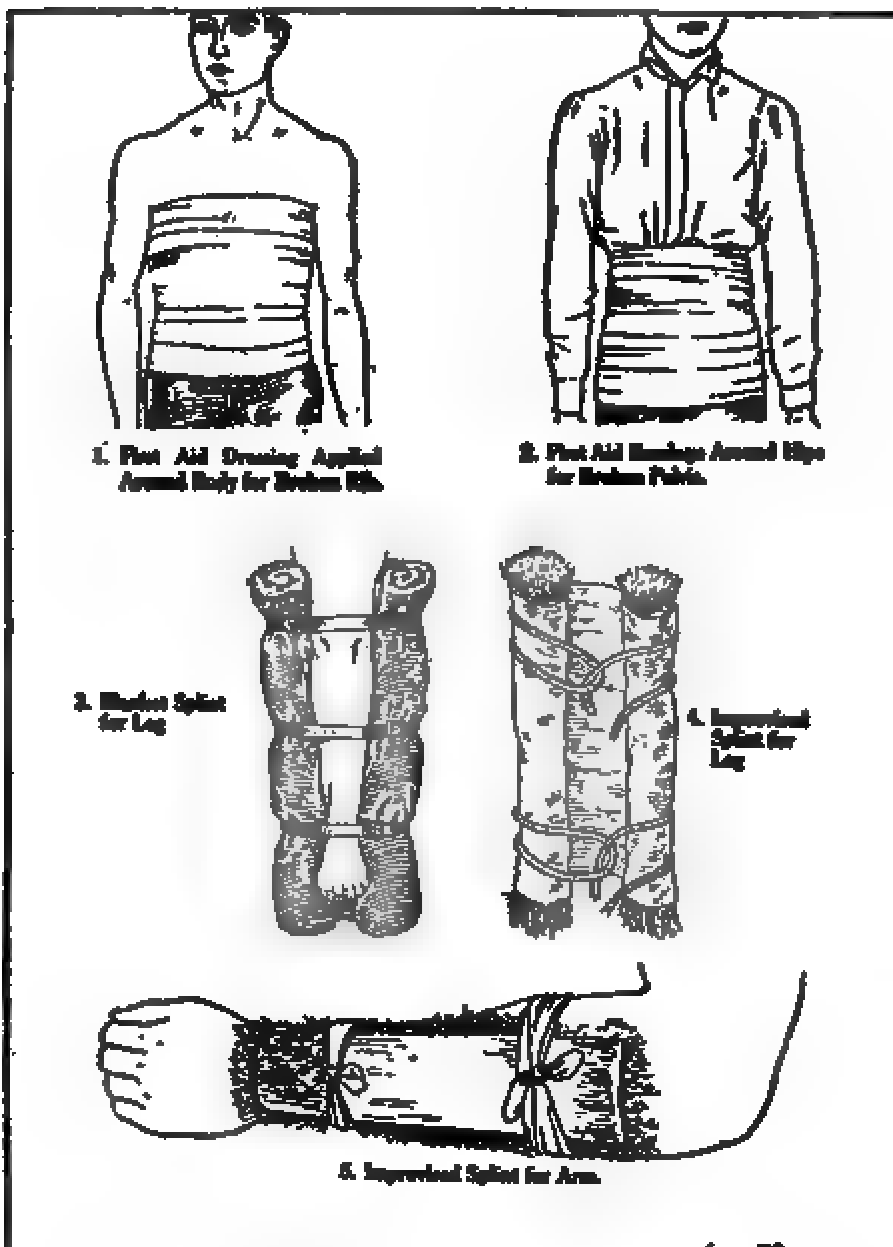


FIG. 122.—Temporary splints. (*American Red Cross.*)

FRACTURE OF THE LEG (BETWEEN THE KNEE AND ANKLE)

The leg extends from the knee to the ankle and has two bones, tibia and fibula.

Fracture of the leg may be simple or compound. Both bones may be broken or only one; the line of fracture may be oblique or transverse. When both bones are broken at the middle or lower third the deformity is usually quite marked. The break is apt to be in an oblique direction and at a lower level in the tibia (the shin) than in the fibula. In simple fracture of the upper part of the leg the deformity may be less marked, but if the knee is involved there may be great swelling because of acute and serious inflammation of the joint.

When the shaft of only one bone (the tibia or fibula) is broken there is not much displacement, because in such cases the sound bone acts as a side splint. Fracture at the lower end of the tibia at the projection on inner side of ankle is sometimes mistaken for sprained ankle, and if the small fragment of bone is not accurately adjusted and kept in proper position the result may be a weak and stiff joint.

The fibula may be fractured at any point, but the important fracture of this bone is known as "Pott's fracture" (Fig. 121). This fracture occurs about 3 inches above the ankle, on outer side of the leg, and is accompanied or complicated by outward dislocation of the foot, and not infrequently by the breaking or tearing off of the tip of the lower end of the tibia.

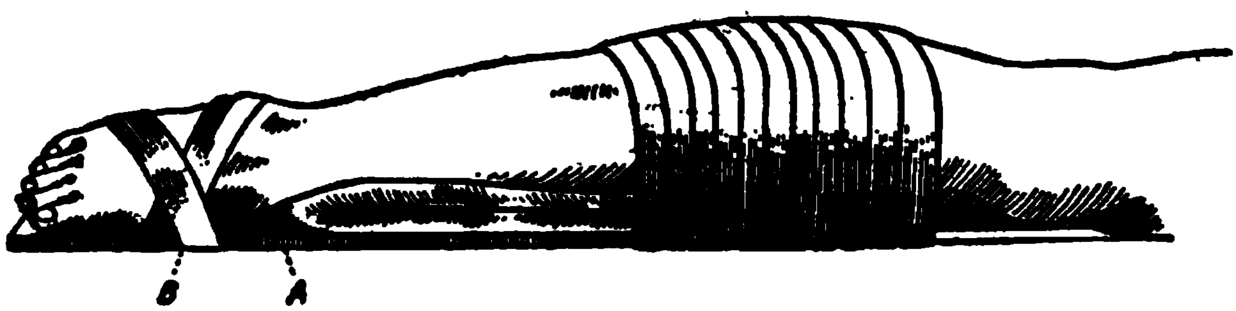


FIG. 123.

Treatment.—If the line of fracture is oblique the limb must be handled very carefully so as to prevent injury to the soft parts by the sharp ends of the bone and thus avoid the conversion of a simple fracture into a compound one.

The treatment of fracture of the leg has been described under the heading "Simple Fractures," page 484.

A Pott's fracture should be treated as follows: Take a board splint long enough to extend from the knee to a few inches beyond the sole of the foot. Pad the splint well, have the lower end of the padding at least 2 inches thick, and do not let it extend quite to the ankle joint below. Apply the splint to the inner side of the leg so that the foot and ankle project below the padding. The foot and leg are then bandaged to the splint in such a way as to turn the foot inward and thus correct the outward displacement (Fig. 123).

FRACTURE IN FOOT

If a bone in the foot is broken, have the patient place his sound foot on a thin board or heavy pasteboard. With a lead pencil draw an outline of the foot, allowing an eighth of an inch extra all the way around. Cut this out, turn it over, and it will fit the sole of the injured foot. Pad this and bind it to the foot, the starch bandage making an excellent dressing. Leave the toes exposed for observation of the circulation.

DISLOCATIONS

A bone is dislocated or "out of joint" when it is displaced or forcibly separated from another bone entering into the composition of a joint.

Dislocations may be complete or incomplete. A dislocation is complete when the joint surfaces are entirely separated and the ligaments torn, as in dislocation of the hip joint; incomplete when the joint surfaces are not entirely displaced. Dislocations may be simple, compound, or complicated.

A dislocation is simple when there is no wound of the skin and soft parts when the joint surfaces are not exposed to the outer air; compound when there is an open wound and the outer air is brought into contact with the joint surfaces of the joint; complicated when besides the dislocation there is a fracture and serious damage to the soft parts or to blood vessels or nerves.

Dislocations are said to be most common in adult or middle life, when the bones are strong and the muscles powerful. In the young and old the bones are more apt to break. There are, however, striking exceptions to this rule when applied to the elbow joint and the shoulder joint. The elbow joint in young subjects is frequently dislocated, and dislocation of the shoulder joint in old men is not uncommon.

Symptoms and Signs of Dislocations.—Deformity is always present, and may be determined by comparing the injured side with the sound one. The head or end of the bone is in an abnormal position; the attitude of the limb is changed; the patient can not move the limb; and when effort is made to move the joint it is found to be very stiff. There may be shortening or lengthening. For example, in dislocation of the hip the head of the thigh bone may be thrown outward and upward, when there will be shortening of the leg; or it may be forced downward and inward, when the length of the limb will be increased.

Treatment.—The indications are to replace the bones in their natural position and to keep the parts at rest until the ligaments and damaged tissues about the joint are healed. A dislocation should be reduced immediately after the accident, while the patient is faint and the muscles are in a relaxed condition.

Having thus briefly described a dislocation and the treatment indicated, the question now arises, How shall the treatment be applied; how shall the dislocation be reduced? And when it is taken into consideration that the reduction of dislocations not infrequently taxes the skill of the most experienced surgeon (even with the aid of general anesthetics), it is hardly to be expected that a non-professional man will be able to accomplish the desired results in many cases. It must also be borne in mind that there are certain dangers attending efforts at reduction, especially at the larger joints, if improperly or too forcibly applied, such as fracture of bone or rupture of blood vessel.

DISLOCATION OF THE FINGERS

Dislocation of the bones of the fingers may be backward or forward.

Treatment.—Extension and counter extension and manipulation. Pull the finger directly in line with the hand, and when fully extended make pressure on the head of the bone. Reduction is usually affected without much difficulty. Place the finger on a well-padded splint for one week, then make passive motion by gently bending it each day, and, if necessary, reapplying the splint after each daily exercise.

DISLOCATION OF THE THUMB

Dislocation of the thumb may be backward or forward.

Treatment.—The treatment is not the same as for dislocation of the fingers, and reduction, especially of the backward dislocation, is usually very difficult. Try by pushing the end of the thumb upward and backward until it stands perpendicularly on the bone from which it is dislocated, then make strong pressure against the base of the dislocated bone from behind forward, sliding it on the bone beneath till it gets to the end, then flex or bend the thumb into place.

DISLOCATION OF THE WRIST

Dislocation of the wrist joint may be backward or forward. It is a rare injury. Fracture about the wrist is more common, and is sometimes mistaken for dislocation. A stiff joint is apt to be the result.

Treatment.—Extension, counterextension, and direct pressure. Grasp the hand of the patient, pull in a straight line, and have an assistant pull on the forearm in the opposite direction, and when the parts are fully extended make direct pressure upon the wrist bones. Apply a bandage, and place the hand and forearm on a well-padded splint for a week; then remove the splint and make passive motion at the joint each day by gently bending the wrist in all directions, reapplying the splint after each daily exercise;

reapply the splint and remove it after an interval of another week. If there is much pain or swelling after reduction of the dislocation, apply cold water.

DISLOCATION OF THE ELBOW

Dislocations of the elbow are serious accidents. They present a variety of forms, backward, forward, outward, and inward, and these are divided into a number of subvarieties. One or both bones may be involved, and the dislocation may be associated with fracture. Reduction in some cases is comparatively easy; in others it is very difficult, even in the hands of experienced surgeons.

Without a thorough knowledge of the anatomy of the normal joint it is very difficult to understand the different forms of dislocation, and of necessity equally difficult to apply the proper treatment.

Immediately after the accident and before swelling sets in, the injured elbow should be carefully compared with the sound one. When the normal arm is extended (straight), the tip of the elbow and the bony points on either side should be in a transverse line across the joint. If these prominences are found out of line, dislocation or fracture is probably present.

Treatment.—Fixation of the arm above the elbow, extension or flexion of the forearm, and direct pressure by means of the thumbs or fingers on the head of the dislocated bone, so as to push it back into the socket. After reduction an angular splint should be applied to inner side of arm, lightly bandaged, and the forearm carried in a sling. Cold water may be applied to reduce inflammatory action. Passive motion should be employed at the end of a week, by gentle movements of the joint each day.

DISLOCATION OF THE SHOULDER

Dislocation of the shoulder joint is a very common accident. It occurs as frequently as all other dislocations put together. The frequency is explained by the great latitude of motion of the joint, the shallowness of the socket, and the size and rounded shape of the head of the bone, the laxity of the capsular ligament, and the leverage exerted on the joint by the long bone.

There are three chief forms of dislocation of the shoulder: (1) forward and downward below the collar bone; (2) directly downward into the armpit; and (3) backward on the shoulder blade.

The symptoms and signs are pain, swelling, rigidity (stiffness), loss of power, flattening and angular appearance of the shoulder as compared with the other shoulder, abnormal situation of the head of the bones, and change in the axis of the long bone (Fig. 124). In the first variety, the most common of all, the head of the bone may be left in front of the armpit and below the collar bone, and the elbow points outward and backward. In the second the head of the bone may be felt in the armpit, and the elbow points outward. In the third the head of the bone may be felt on the back of the shoulder blade, the elbow points forward, and the forearm is thrown across the chest. Another valuable sign is that when the elbow is placed on the chest the patient can not place the hand of the injured side upon the opposite shoulder, or, if the hand is placed on the shoulder the elbow can not be brought into contact with the chest.

Treatment.—The treatment for the first variety (forward and downward) is as follows: Lay the patient down or let him sit on a chair; bend the forearm on the arm; press the elbow against the side of the chest and hold it there; rotate the arm outward by carrying the forearm outward; pull steadily on the arm and rotate inward by carrying the elbow upward and forward with forearm across the chest. While this is going on have an assistant place his hand in the armpit and press the head of the bone into place.

For the second variety (directly downward into the armpit) place the patient on his back; remove your boot; place your heel in the armpit; grasp the wrist and pull steadily on the arm. If the dislocation is in the right shoulder, seat yourself on the right side of the patient and use your right foot; and if the injury is in the left shoulder, seat yourself on the left side and use your left foot. The same principles may be carried out by seating the patient on a low chair and placing your knee in the armpit.

Another method is to have an assistant stand upon a table and make counterextension with a towel, or a strong piece of soft cloth of any kind, passed under the armpit of the patient, while the operator pulls the arm downward. The same method may be employed by causing the patient

to lie on his back, and an additional advantage may be obtained by placing a rolled bandage or a pad of any kind in the folds of a towel in the armpit.

In dislocation backward on the shoulder blade, pull the arm forward and make direct pressure forward on the head of the bone, or stand behind the patient, draw the elbow backward, and with the thumb press upon the head of the bone and guide it into place.

After reduction a soft pad should be placed in the armpit, the upper arm bandaged to the body, and the forearm placed in a sling across the chest. Passive motion at the joint should begin at the end of a week and be repeated daily by grasping the arm and gently moving the shoulder in all directions. The arm should be carried in the sling about three weeks.

FIG. 124.—Dislocation of the right shoulder.

DISLOCATION OF THE COLLAR BONE

The collar bone extends from the upper border of the breast bone to the highest point of the shoulder blade. Dislocation may occur at either end. Reduction is comparatively easy, but it is difficult to retain the bone in position.

Treatment.—Make extension by drawing back the shoulders, the knee, if necessary, being placed between the shoulder blades; push the end of the bone in place and try to keep it there by a firm pad fastened by adhesive plaster and bandage. The best result may be obtained by placing the patient at rest on his back for three weeks.

DISLOCATIONS OF THE TOES

Dislocations of the toes are very rare accidents. The treatment is the same as for dislocation of the fingers. Dislocation of the big toe may be treated the same as dislocation of the thumb.

DISLOCATION OF THE ANKLE

The foot may be dislocated forward, backward, outward, inward, or upward. The dislocation may be complete or incomplete.

The lower ends of the bones of the leg enter into the formation of the ankle joint, the end of the tibia on the inner side, and the end of the fibula on the outer side of the joint. Dislocations of the ankle are usually complicated by fracture of the tip of one or both of these bones. When, in addition, the fibula is broken above the ankle the injury is known as Pott's fracture, already referred to.

Treatment.—Extension, counterextension, and pressure. Flex the leg on the thigh and the thigh at right angle to body; pull steadily on the foot, while an assistant makes counterextension at the thigh, and press the bones in place. Apply cold water and place the foot and leg in a fracture box or apply well-padded molded splints. Binder's board dipped in warm water and molded to the part and lined with thick layers of cotton will answer the purpose. If a Pott's fracture, use the splint shown in Fig. 123. Make passive motion at the joint at the end of two weeks. (See method described under dislocation of the elbow.)

DISLOCATION OF THE KNEE

Dislocation of the knee may be complete, incomplete, compound, or complicated. The direction of the dislocation may be forward, backward, outward, or inward. The deformity is quite marked. Reduction is not very difficult, but the injury is a serious one and care must be taken in making reduction not to produce additional damage by too forcible extension. Fortunately the injury is exceedingly rare.

Treatment.—Extension, counterextension, and pressure. Have one assistant pull steadily, not too hard, on the leg or ankle, while another fixes or pulls on the thigh and presses the bone into place. After reduction apply cold water, and place the leg in a posterior straight splint, well padded especially below the hollow of the knee, and make passive motion at the end of two weeks. When the patient begins to walk, a kneecap or flannel bandage should be applied.

DISLOCATION OF THE HIP

Dislocation of the hip joint is a serious injury. It occurs much less frequently than dislocation of the shoulder joint. The socket of the hip joint is very deep, and the ligaments and muscles surrounding the joint are very strong and powerful. Dislocation occurs only when the limb is in a certain position, when its axis is changed from that of the body, and when in consequence of any sudden or great force received on the lower end of the leg or knee the head of the bone is forced through the ligament (the capsule) which surrounds the joints. The head of the bone may then be thrown (1) backward and upward; (2) backward; (3) forward and downward; (4) forward. The different directions indicate the different forms of dislocation. The first is the most common.

In the first form, examination from below up shows the big toe turned toward or resting on the instep of the opposite foot; the knee flexed and resting against thigh at upper margin of opposite kneecap; the thigh rotated inward and drawn toward its fellow; bulging of the hip; and about 2 inches shortening of the entire limb.

In the second form the signs are the same as in the first, but less marked. (Fig. 125). Fracture of the neck of the thigh bone is somctimes mistaken for this injury. But in fracture there is abnormal motion, and the foot is turned outward.

In the third form (Fig. 126) the signs are almost exactly the reverse of the first form. The foot and knee are turned outward, the hip is flattened, and the entire limb is lengthened.

The signs of the fourth form are nearly the same as those of the third except that the entire limb is shortened.

Treatment.—The treatment is by manipulation or by extension and counterextension.

For the first and second forms of dislocation, the above described treatment may be applied as follows: Place the patient on his back on a mattress on the floor. Seize the foot or ankle with one hand and place the other

hand under the knee. Flex the leg upon the back of the thigh, and the thigh upon the body to about a right angle; then carry the knee inward and rotate on its own axis, then suddenly raise it (lift it toward the ceiling) so that the head of the bone may be thrown over the rim of the socket, and immediately extend the limb with outward rotation to its normal position so that the head of the bone may return to the socket through the hole in the capsule by which it escaped.

The treatment of the third and fourth forms of injury corresponds to that for the first and second, except that the limb should be carried outward first, then inward, across the median line, and rotated inward on its own axis, and then suddenly lifted and brought down to its normal position by the side of its fellow.

FIG. 125.

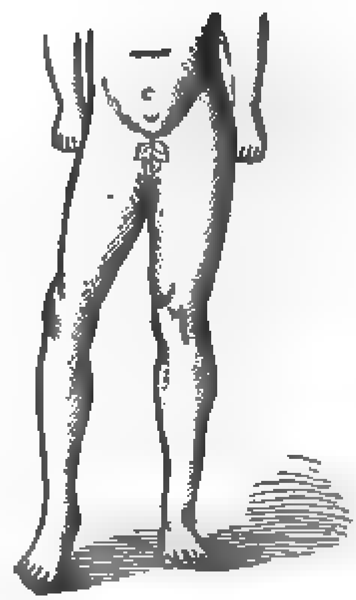


FIG. 126.

No great force should be used in making these movements. If any considerable resistance is met with in rotating or lifting the bone, the movement should be modified in such a way that the head of the bone may follow the path of least resistance.

If extension and counterextension be applied, they should follow the line of the axis of the dislocated thigh. It must not be forgotten in the consideration of these methods that the application of too much force or of force improperly applied may produce fracture of the bone.

CHAPTER XIII

OFFICE PRACTICE

The treatment of Office Practice will be handled in the same manner as the Survey; that is under the Main Divisions of

(*a*) The Improvement of Existing Roads.
(*b*) The Location of New Roads.

It is impossible in a book of this character and size of page to illustrate exactly the detail methods of design which carry out the principles of economy discussed in Part I but we have made an effort to give an idea of the practical methods by restricted examples and rather full instructions for drafting room procedure which the author has used in instructing men not familiar with the details of road work.

We have in mind getting out in the next year or so data in treatise form containing large charts and plates to illustrate in detail the office methods of economical alignment and grade line design.

The collection of tables in this chapter have been found from actual office use to be of value in saving time in the design and estimate of quantities.

LIST OF TABLES IN CHAPTER XIII

For stream runoff, capacity of culverts, bridge loading, safe loads on piles, safe loads on foundation soils for structures, etc., see Chapter III on Drainage.

For Depths of Macadam roads on different soils, see Chapter V on Foundation Courses, page 152.

(a) The Improvement of Existing Roads

Under office practice we include

1. Mapping the preliminary survey.
2. Designing the improvement and estimating the quantities.
3. Producing a finished set of plans from which the road can be constructed.

1. MAPPING THE PRELIMINARY SURVEY

The mapping of the preliminary survey serves as a base from which the design of the new work, and the quantities necessary thereto, can be built up. It consists of three views of the road: the plan, showing the topographic features; the profile, showing the longitudinal differences of elevation, and the cross-sections, showing the constantly changing transverse shape.

The scales in general use are as follows:

Plan	Profile	Cross-sections
1″ = 100′	1″ = 100′ horizontal 1″ = 10′ vertical	1″ = 10′
1″ = 50′	1″ = 50′ horizontal 1″ = 10′ vertical	1″ = 5′ or 1″ = 4′
1″ = 20′	1″ = 20′ horizontal 1″ = 5′ vertical	1″ = 5′ or 1″ = 4′
1″ = 10′	1″ = 10′ horizontal 1″ = 10′ vertical	1″ = 2′

The 100′ scale is too small for convenience in design, and earthwork quantities figured from cross-sections plotted 1″ to 10′ are not reliable. For work on ordinary country roads, the 50′ scale is generally adopted, using cross-sections plotted 1″ to 5′ or 1″ to 4′; this scale is satisfactory for laying the grade line and computing the earthwork.

The larger scales of 1″ = 20′ or 1″ = 10′ are useful in village work where a large amount of detail must be shown.

Plotting the Center Line.—The survey center line can be plotted by deflection angles at the transit points, using a table of natural tangents, a vernier protractor or an ordinary paper protractor graduated to 15 minutes.

Where the center line has been well located in the field and there seems to be no necessity for a paper re-location, no great care need be taken in plotting the deflection angles, as in such a case the map serves more as a picture of the topographic features than as a basis for alignment.

Where a random line has been run in the field and some shifting of the center line is necessary, both angles and distances must be accurately plotted. If any extensive change of alignment is made, the new deflections and distances should be checked by figuring the difference of latitude and longitude for both the survey line and the office line between the points of equality.

Where the consideration of sight distance (see page 33) governs, Table 36 will be of service.

TABLE 36

Table 36 gives the approximate distance that an automobile driver can see an approaching car, assuming that he is driving in the center of the macadam and that the approaching car is also in the center. Two distances are given for each curve, the first assuming that the line of sight is six feet from the ground, which is about right if the curve is on a straight grade, and makes the line of sight tangent to the cut slope of 1 on 1½ 19 feet off center for the narrow section shown in Fig. 11, page 44, and, second, assuming that the line of sight is close to the ground, as occurs on rounding the top of a hill, in which case the line of sight will be tangent to the side slope at, approximately, 11′ off center.

Degree of Curvature	Radius of Curve Feet	Sight Distance Case One. Feet	Sight Distance Case Two. Feet
5	1146.0	400	310
6	955.0	375	290
7	818.6	350	270
8	716.3	330	250
9	636.6	310	235
10	573.0	295	220
12	477.5	270	200
14	409.3	245	185
16	358.1	230	175
18	318.3	220	165
20	286.5	210	160
30	191.0	170	130
40	143.2	145	110
50	114.6	130	100

For convenience in plotting the topography, the 100′ survey stations are plainly marked.

The most common mistakes in plotting the map are made by reversing the deflection, as right instead of left and *vice versa*, or in adding or omitting 100′ in scaling long-tangent distances. The work should be checked for mistakes of this nature.

All curve data is marked plainly on the map near the *P.I.* and shows

The deflection angle Δ
The degree of curve D
The radius of curve R
The tangent length T
The length of curve L
The station of the *P. I.*
The station of the *P.C.*
The station of the *P.T.*

If the curves have been figured in the office and have not been run in the field it is good practice to scale the offsets from the tangent to the curve and mark them on the map.

These offsets from the center line as run are then transferred to the cross-sections and the profile plotted from center line elevations on the cross-sections.

Plotting the Topography.—If the topography has been recorded by a system of right-angle offsets, as suggested and illustrated on page 328, it can be easily and quickly plotted by using the transparent scale shown here.

This scale gives the plus distance along the survey base line, or center line, and the offset distance from the line in one operation.

As a general rule the plotting of the topography need not be checked.

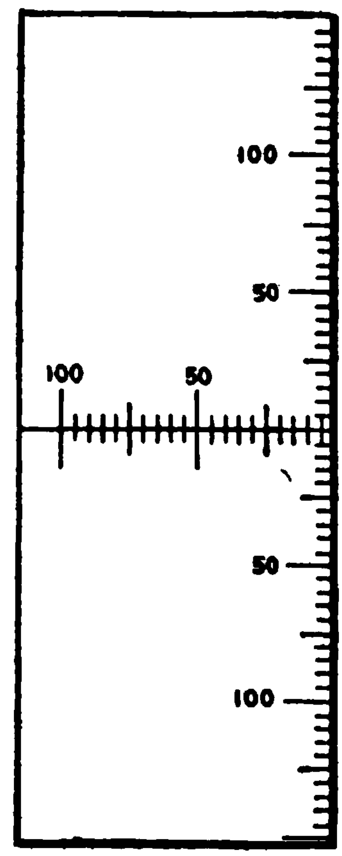


FIG. 127.—Convenient transparent scale for plotting topography.

Level Computations.—The survey computations of the Bench Levels are checked and a list of bench elevations prepared; these elevations are used in cross-section level notes and from them the notes are computed between benches. As each bench is reached these notes are corrected to agree with the elevation adopted for that bench and then carried forward on the corrected basis. The allowable error for cross-section levels, as mentioned in the chapter on surveys, is less than 0.1 foot. The correction of the levels at each bench prevents any cumulative error and makes the elevations of the cross-section shots agree with the adopted bench elevations with an error of less than 0.1′. This is as close as the readings can be plotted and as close as they can be read in the field.

The computation of the bench levels and the adjustment of the cross-section notes should be checked by a competent man. The most common mistake in figuring the cross-section readings is to use the wrong height of instrument for a section. Such a mistake can not be detected in plotting the sections, but is generally discovered when the profile is plotted.

In checking the notes particular care should be taken on this one point.

Potting the Cross-sections.—The cross-sections must be *very carefully* plotted, as the reliability of the earthwork computation depends largely on their accuracy.

The cross-section paper used should be exact in the divisions and should be printed or engraved from plates.

Ruled paper is inaccurate.

The plotting is checked by reliable men. Reading the shots back from the plotted cross-section is preferable to reading them from the book. The elevations of the center line and of the ditch line are written over the section. The station number or plus of each section is written on the right margin. The fact that

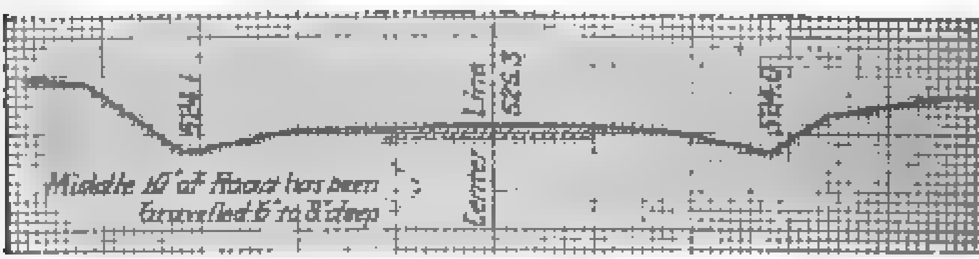


Fig. 128.

the section has been graveled within the traveled way, that stone has been spread to a certain thickness, or any other fact that would influence the designer when laying a grade line, is noted on the section. See Fig. 128.

It is common practice to allow the inexperienced men to plot and check the cross-sections. We believe this is a mistake. This part of mapping is the most important of the preliminary plans, and the work should be plotted and checked so that the points are correct to the nearest 0.1 feet in elevation.

These points are then connected with a fine ink line.

Plotting the Profile.—The profile is plotted from the center-line elevations given in the cross-section notes unless the proposed center line does not coincide with the survey center line, in which case the elevations of the proposed line are projected from the previously plotted cross-sections.

It is not necessary to spend so much time for accuracy in plotting as on the sections, as the profile only serves as a guide in laying the grade line and no quantities depend upon its correctness. An error of 0.2 feet is allowable.

The elevation of each plotted center-line point is recorded with its stationing (see Figure 131, page 510).

The Design.—The completion of the profile finishes the preliminary mapping. The first operations of the office design are as follows:

A. The selection of section.
B. The depth of metalling.
C. The laying of the grade line.

These three points are so dependent on each other that they cannot be separated.

The most experienced man available should do this part of the work. He should be thoroughly familiar with the road from field inspection, and in designing he follows the general principles discussed in the chapters on Grades, Sections, and Foundations. His selection depends on a report of the character given in the chapter on Preliminary Investigation (see page 274).

Maximum gradients for the various types of pavement are as follows:

Wooden block	2%
Asphalt block	4%
Brick	5%
Concrete	5%
Bituminous macadam with flush or squeegee coat	4%
(In sandy country, six per cent. when coarse sand is sprinkled on surface.)	
Bituminous macadam without squeegee	8%
Waterbound macadam	8%
"Hillside" brick	12%
Stone block with open joints	12%

Shrinkage of Earthwork.—We have made no mention heretofore of the shrinkage of earth cut when placed in fill. This is an important factor of an economical grading design.

Trautwine states that for railroad work it takes

1.08 cu. yd. gravel or sand excavation to make 1 cu. yd. embankment.

1.10 cu. yd. clay excavation to make 1 cu. yd. embankment.

1.12 cu. yd. loam excavation to make 1 cu. yd. embankment.

1.15 cu. yd. vegetable surface soil excavation to make 1 cu. yd. embankment.

The quantities 1.08 cu. yd. gravel, etc., refer to the volume occupied by the material before removal.

Trautwine also states that in loosening earth and loading into wagons or cars 1 cu. yd. of earth swells about one-fifth and measures loose practically 1.2 cu. yd.

These values, however, cannot be used in roadwork, as a certain percentage of the excavation is sod or vegetable matter that is not suitable for embankment and must be wasted.

This waste material raises the percentage of cut necessary to make the fill.

The correct ratio for roadwork has been a source of contention

among engineers, and we believe that the use of too high a value has resulted in a needless waste of thousands of dollars during the last five years in New York State alone.

Under this head it may be stated that on several roads under the supervision of W. G. Harger, a careful study of this point was made, taking unusual care with the original and final cross-sections, the plotting and planimeter work, and it was found that for the cases investigated, the ratio of cut to fill varied from 1.15 in heavy cuts to 1.27 in light skimming work.

It is the general opinion among engineers of Division 5, N. Y. S. Dept. of Highways, that the percentage formerly used (namely 1.35) is too high. In nearly all cases where the work was at all heavy, a large excess of dirt had to be wasted. There have been some roads designed on a basis of 1.35 where more dirt was needed, but in the author's opinions this was due to discrepancies in the field or office work or by allowing the contractor to use the roadbed excavation for filler or concrete material. If the soil encountered is suitable for such purposes, it is plainly up to the contractor to furnish other material for the places excavated.

The authors believe that the following ratios will be satisfactory for ordinary cases:

TABLE 32

Light skimming work, large amount of heavy sod	1.35
Light skimming work, considerable sod	1.30
Light skimming work, not much sod	1.25
Medium work	1.20
Heavy work	1.15

Trautwine's earth ratios are correct where earth borrow is obtained from a pit.

Trautwine states that 1.0 cu. yd. of solid rock, when broken up, will make 1.66 to 1.75 cu. yd. of rock fill.

In this statement he assumes that the fill is made of stone alone and that the voids are not filled. In most roadwork, the small quantities of rock encountered are dumped in with the earth as embankment, and as the voids are all filled with earth it is evident that 1 cu. yd. of rock will make only 1 cu. yd. of fill; however, if a large unmixed stone fill is made, his ratio holds.

The discussion of these ratios has been carried out to some length because we believe it is one of the points that illustrate the advantage of careful engineering. Several of the New York State plans, the cost of which has ranged from \$100 to \$200 per mile, have been revised with this end in view; the revision costing an additional \$15 to \$30 per mile, with a resultant saving in construction cost of from \$200 to \$700 per mile.

The use of a rolling grade was recommended in the chapter on Grades. The designer is cautioned, however, not to carry this to extremes as there are many short, small hummocks which must be disregarded if a reasonably good profile is to be obtained. Figure on page 509 indicates a proper and improper use of an undulating profile.

Templets.—For the convenience of the designer in drawing the shape of the finished road on the cross-sections, a number of transparent composition templets are made, cut to proper scale, representing the different shaped sections to be used. See Figs. 129 and 130.

Economical Grade Line.—On page 26, the most economical grading conditions were mentioned. A convenient method of

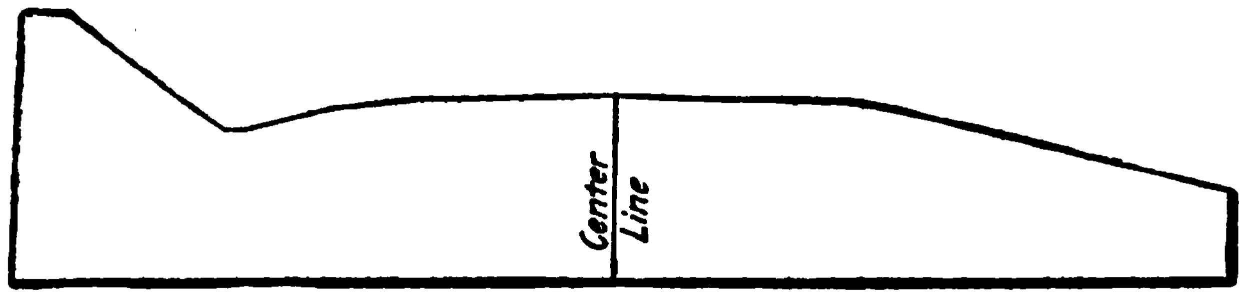


FIG. 129.—Transparent templet for use on cross-sections giving finished shape of road.

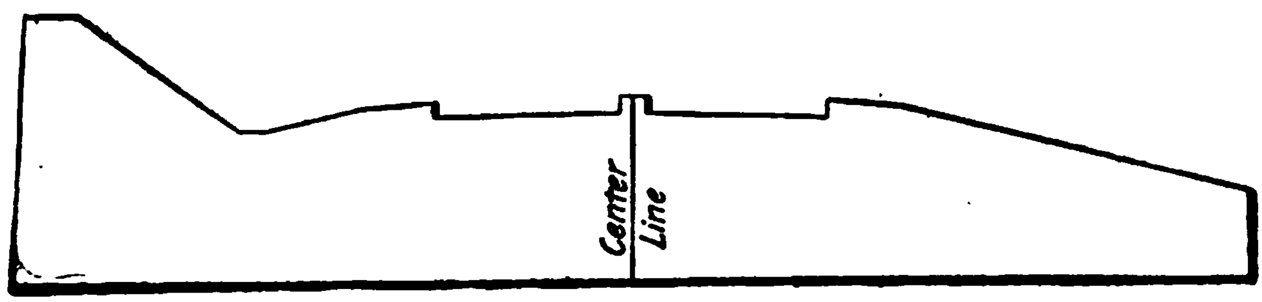
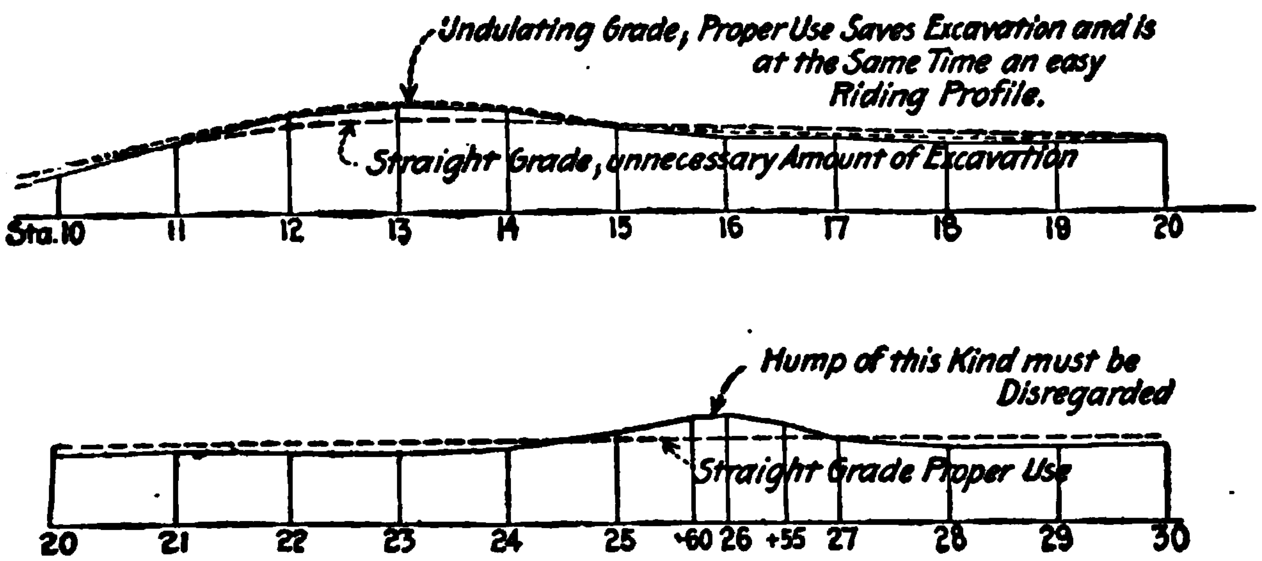


FIG. 130.—Transparent templet with stone trench cut; saves time in drawing in sections for figuring cut and fill.



Illustrating Proper Use of
Straight and Undulating Grades.

-ing a grade line that will approximate these conditions is as -lows: take the case of determining an economical profile for a -ad from station 11 to station 16, where the grade can be placed any desired elevation (see page 510). Place the adopted templet each cross-section so that the cut will just make the fill (this -ition is estimated) and note the elevation of the center line of the

proposed finished road for this position of the templet; mark this elevation on the profile for each section between stations 11 and 16; to connect these points would give the most economical grade line, but this can rarely be done with a resulting smooth profile. The adopted grade is obtained by drawing in a smooth grade line, that averages the elevations of these points and varies in elevation above or below them as little as possible.

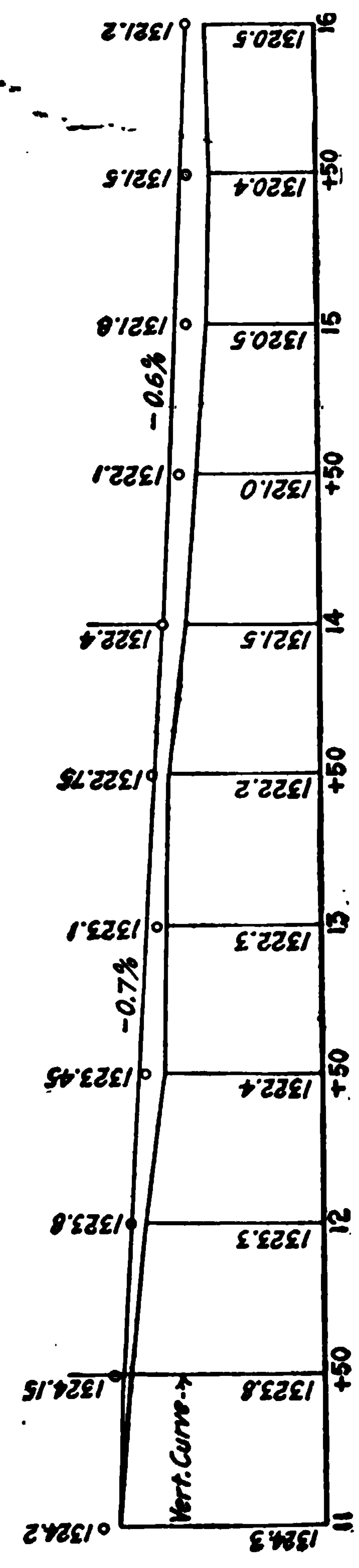


FIG. 131.—Sample profile illustrating method of placing economical grade line.

NOTE.—The small circles show the elevation of grade at each section that would make the proposed cut just make the proposed fill at that section.

The adopted grade elevation at each station is then figured, the shape of the finished road drawn on the cross-sections at these elevations, and the excavation and embankment computed. If the ratio of cut to fill is not correct, the grade is raised or lowered slightly to produce the desired ratio. This method is illustrated in Fig. 131.

For each stretch of road where economy of grading governs the profile, this procedure is repeated, and for the sections of road where other considerations govern, the grade is placed at the required elevation and the borrow, waste, or overhaul figured.

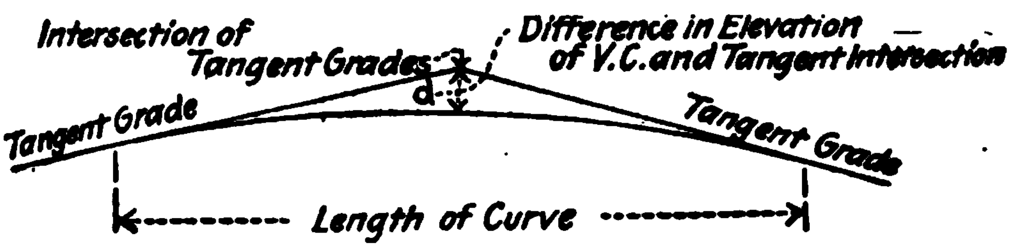
To obtain a smooth grade line vertical curves are used at the intersection of the different tangent rates of grade. Vertical curves are not usually used where the difference in rates of grade is less than ½ per cent.

For the final plans these vertical curve elevations may be computed by the following formulæ, but for the trial grade line they can be scaled from the profile, drawing in the curve by means of a regular curve templet, with which all modern offices are equipped, and in all ordinary cases this graphic method serves for the final grade line as with reasonable care the elevations are closer than can be constructed.

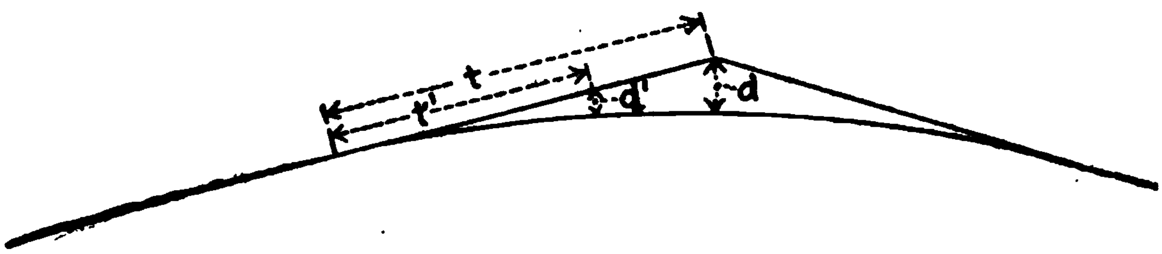
V. C. Formulæ:

Formula A. Difference in elevation at Center of Curve.

d expressed in feet = ⅛ (Algebraic difference of the tangent grades expressed in feet per 100) × (length of curve expressed in stations of 100′).



FORMULA A

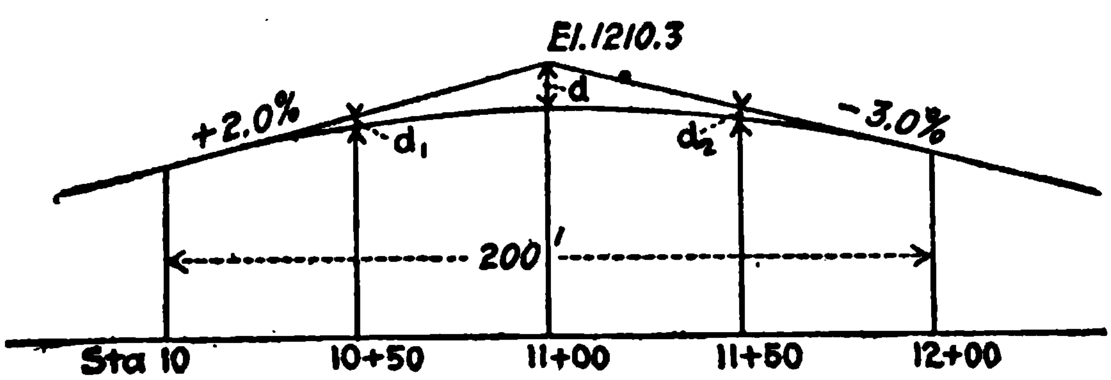


FORMULA B

Formula B. Intermediate differences of Elevations between tangent grades and points on vertical curve.

$$d' : d :: t'^2 : t^2$$

$$d' = \frac{dt'^2}{t^2}$$



EXAMPLE OF VERTICAL CURVE COMPUTATION

It is required to figure the vertical curve elevations for a vertical ɪrve 200′ long between tangent grades of + 2.0% and −3.0% eeting at station 11 + 00 at an elevation of 1210.3.

First, find the middle correction d: use formula A.

$$d = \tfrac{1}{8}\,(2.0 - (-3.0)) \times (2)$$
$$d = \tfrac{1}{8}\,(5) \times (2) = \tfrac{10}{8} = 1.25'$$

Second, determine the corrections d_1 and d_2; use formula B.

$$d_1 = \frac{dt'^2}{t^2} = 1.25\,\frac{50^2}{100^2} = 1.25 \times \tfrac{1}{4} = 0.31 \text{ foot}$$

$$d_2 = 1.25\,\frac{50^2}{100^2} = 0.31 \text{ foot.}$$

Third, determine the elevation of the tangent grades at 10 + 50 and 11 + 50.

Fourth, subtract the *V.C.* corrections d_1, d, and d_2 from these tangent grades at 10 + 50, 11 + 00 and 11 + 50.

VERTICAL CURVE ELEVATIONS

Sta. 10 + 50 =	Tangent Elev.	1209.3	− 0.31	=	1208.99
" 11 + 00 =	" "	1210.3	− 1.25	=	1209.05
" 11 + 50 =	" "	1208.8	− 0.31	=	1208.49

The following table, No. 37, is useful for draftsmen in picking out the correct curve to use in inking in the vertical curves. This table is compiled for a horizontal scale of 1″ = 50′, and a vertical scale of 1″ = 10′. For other scales a similar table can be constructed.

Explanation of Table 37.—Suppose it is required to pick out the correct curve templet to draw in a vertical curve 300′ long between two tangent grades having an algebraic difference of 5 per cent. (say a + 2.0 per cent. grade and a − 3.0 per cent. grade). On the line opposite 5.0 in column 1 representing the algebraic difference of rate, pick out the value 24 in the column headed 300′ curve; this means that a curve having a radius of 24 inches will fit the conditions. This curve can be found easily from the collection of curve templets which have been previously marked with their radii in inches.

The limit of sight due to vertical curves is shown in Table 38.

Table 38 gives the distance ahead that a driver can see on a straight road, assuming that his eye is 6 feet above the road, for vertical curves of 200 feet, 150 feet, and 100 feet long between grades having a large difference of rate.

Example. Suppose a plus 5 per cent. grade meets a minus 7 per cent. grade and that it is desired to put in the minimum length curve that will allow a sight ahead of 300 feet. The difference in gradient is 5 + 7 = 12 per cent. From Table 38, opposite 12 per cent., we can readily pick the length required; it will be about 170 feet and 200 feet would probably be used. It is rare that the sight distance governs in the selection of length of curve.

Placing the Templets and Planimetering the Areas.—After the trial grade line has been placed the center line elevations of the proposed finished road are figured for each point on the profile where cross-sections have been taken and the section selected is drawn on the original cross-sections at these elevations, using the templets mentioned above.

Because it is comparatively easy to make a mistake of one foot or five feet in elevation, the elevation of new grade, as shown

Table 37. Table of Radii for Plotting Vertical Curv on Profiles

Algebraic Diff.	100′ Curve Rad.	200′ Curve Rad.	300′ Curve Rad.	400′ Curve Rad.
1.0	40	80	120	160
1.2	33	67	100	132
1.4	29	57	85	116
1.6	25	50	75	100
1.8	22	44	65	88
2.0	20	40	60	80
2.2	18	36	55	72
2.4	16½	33	50	66
2.6	15½	30	46	62
2.8	14½	29	43	58
3.0	13½	27	40	54
3.2	12½	25	37	50
3.4	12	23	35	48
3.6	11	22	33	44
3.8	10½	21	32	42
4.0	10	20	30	40
4.5	9	18	27	36
5.0	8	16	24	32
5.5	7	14½	22	28
6.0	6½	13½	20	26
7.0	6	11½	17	24
8.0	5	10	16	20
9.0	4½	9	13½	18
10.0	4	8	12	16
11.0	3½	7	11	14½
12.0	3½	6½	10	13½
13.0	3	6	9	12½
14.0	3	5½	8½	11½

Table 38

Difference in Rate of Grades	Sight Distance for 200 ft. V. C.	Sight Distance for 150 ft. V. C.	Sight Distance for 100 ft. V. C.
8%	—	—	370 feet
10%	355 feet	315 feet	290 "
12%	320 "	290 "	260 "
14%	290 "	260 "	230 "
16%	260 "	230 "	210 "

by the position of the templet, should be checked from the profile before computing the cuts and fills.

Because of the small, irregular shape of these areas it is not possible to compute them arithmetically and the areas are determined by planimeters. Great care must be exercised if the work is to be reliable; a double run is made and the second run should be twice the first area. A certain limit of error in the second area is adopted (see footnote).[1] This method is sufficiently accurate for preliminary estimating. On final estimate work, where the payment for earth excavation depends on the planimeter work, a satisfactory method is to have two men, using separate planimeters, compute the areas independently without any knowledge of each other's result. If the amount of excavation as figured separately varies more than 2 per cent., a third run is made.

The reason that it is difficult to get accurate planimeter results is that the work is monotonous, confining, and hard on the eyes, and the tendency is toward carelessness unless the men know that their work is being checked.

The temptation is strong to make the second reading equal twice the first, and unless some such method is used to check up, small errors will be passed over.

As a matter of interest three miles of planimeter work, checked in this manner, was examined to see the average difference in areas, where two careful men using different planimeters computed their results separately.

The sections used were plotted 1″ = 5′; areas read to nearest 0.1 sq. ft.

The average percentage of difference for single areas was

1. Small areas below 10 sq. ft.........per cent. of difference 5%
2. " " 10 to 30 " " .... " " " " 2%
3. Areas above 30 " " .... " " " " 1%

However, these differences for single areas compensate, as some are above and some below the mean value, and computing the two separate results for the three miles gave the following result.

Percentage differences for work of two men for three miles, showing the reduction of error due to compensation.

1. Small areas below 10 sq. ft. .....per cent. of difference 1.0 %
2. " " 10 to 30 " " ..... " " " " 0.5 %
3. Areas above 30 " " ..... " " " " 0.05 %

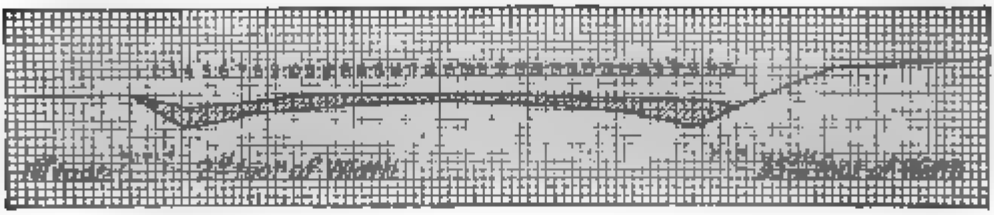
The average excavation per mile will run about 3000 cu. yd., which means the average area of cut is about 16 sq. ft.

This comes under the second division and makes the probable error of final estimate planimeter work sufficiently close for all practical purposes.

Areas by Measuring the Depth of Cut or Fill at Intervals of One Foot Across the Section.—It is often necessary for the field men to make a change in grade or alignment, and the following method of

[1] A satisfactory rule has been to allow a difference of 0.4 sq. ft. for areas up to 50 sq. ft., and 1.0 sq. ft. error above 50 sq. ft.

estimating section areas is convenient when no planimeter is available. The method is illustrated in the figures shown below:



Measure the depth of the cutting on vertical No. 1. Call this depth 1′. It can be readily seen that this depth is the average depth for the first foot of the cross section, and if multiplied by one foot equals the area of the first foot of the section. In like manner measure the depth of the section on vertical No. 2. This is the average depth of the second foot of the section, and multiplied by one foot equals the area of the second foot of the section. If the sum of the depths 1′, 2′, 3′, etc., is obtained for the entire width of the section it is evident that the sum must equal the area of the section.

This summation can readily be made graphically as shown below by marking off on the edge of a piece of paper the successive depths.

Scale the distance from the reference mark to the end mark, using the same scale by which the cross section is plotted and the area of the section is obtained. This method is as reliable as planimeter work, but is necessarily slower.

Computation of Earthwork.—Earthwork is usually computed from the planimeter results by the method of end areas; where 50 ft. sections are used the following table is convenient.

Explanation of Table 39.—Suppose the area of excavation at, say, station 22 + 00 is 30.6 sq. ft.; suppose the excavation area at station 22 + 50 is 20.1 sq. ft. To get the number of cubic feet of excavation from station 22 + 00 to 22 + 50 add 30.6 + 20.1 = 50.7. In Table 35 an area of 50.7 gives an excavation quantity of 1267.5 cu. ft. Where the normal cross-section interval is 50 ft. this table is a great time-saver.

Table 40 is convenient in changing cubic feet to cubic yards.

Table 41 is convenient for preliminary estimates, as it gives the cubic yards directly for the sum of the end areas in square feet. It, however, is not figured exactly and is not suitable for final estimate work.

TABLE 39. VOLUME OF 50-FT. SECTIONS IN CUBIC FEET FOR SUM OF END AREAS

COMPILED BY J. H. HUBER, ASSISTANT ENGINEER, BUFFALO, N.Y.

Sum of End Areas Sq. Ft.	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
0	—	2.5	5.0	7.5	10.0	12.5	15.0	17.5	20.0	22.5
1	25.0	27.5	30.0	32.5	35.0	37.5	40.0	42.5	45.0	47.5
2	50.0	52.5	55.0	57.5	60.0	62.5	65.0	67.5	70.0	72.5
3	75.0	77.5	80.0	82.5	85.0	87.5	90.0	92.5	95.0	97.5
4	100.0	102.5	105.0	107.5	110.0	112.5	115.0	117.5	120.0	122.5
5	125.0	127.5	130.0	132.5	135.0	137.5	140.0	142.5	145.0	147.5
6	150.0	152.5	155.0	157.5	160.0	162.5	165.0	167.5	170.0	172.5
7	175.0	177.5	180.0	182.5	185.0	187.5	190.0	192.5	195.0	197.5
8	200.0	202.5	205.0	207.5	210.0	212.5	215.0	217.5	220.0	222.5
9	225.0	227.5	230.0	232.5	235.0	237.5	240.0	242.5	245.0	247.5
10	250.0	252.5	255.0	257.5	260.0	262.5	265.0	267.5	270.0	272.5
11	275.0	277.5	280.0	282.5	285.0	287.5	290.0	292.5	295.0	297.5
12	300.0	302.5	305.0	307.5	310.0	312.5	315.0	317.5	320.0	322.5
13	325.0	327.5	330.0	332.5	335.0	337.5	340.0	342.5	345.0	347.5
14	350.0	352.5	355.0	357.5	360.0	362.5	365.0	367.5	370.0	372.5
15	375.0	377.5	380.0	382.5	385.0	387.5	390.0	392.5	395.0	397.5
16	400.0	402.5	405.0	407.5	410.0	412.5	415.0	417.5	420.0	422.5
17	425.0	427.5	430.0	432.5	435.0	437.5	440.0	442.5	445.0	447.5
18	450.0	452.5	455.0	457.5	460.0	462.5	465.0	467.5	470.0	472.5
19	475.0	477.5	480.0	482.5	485.0	487.5	490.0	492.5	495.0	497.5
20	500.0	502.5	505.0	507.5	510.0	512.5	515.0	517.5	520.0	522.5
21	525.0	527.5	530.0	532.5	535.0	537.5	540.0	542.5	545.0	547.5
22	550.0	552.5	555.0	557.5	560.0	562.5	565.0	567.5	570.0	572.5
23	575.0	577.5	580.0	582.5	585.0	587.5	590.0	592.5	595.0	597.5
24	600.0	602.5	605.0	607.5	610.0	612.5	615.0	617.5	620.0	622.5
25	625.0	627.5	630.0	632.5	635.0	637.5	640.0	642.5	645.0	647.5
26	650.0	652.5	655.0	657.5	660.0	662.5	665.0	667.5	670.0	672.5
27	675.0	677.5	680.0	682.5	685.0	687.5	690.0	692.5	695.0	697.5
28	700.0	702.5	705.0	707.5	710.0	712.5	715.0	717.5	720.0	722.5
29	725.0	727.5	730.0	732.5	735.0	737.5	740.0	742.5	745.0	747.5
30	750.0	752.5	755.0	757.5	760.0	762.5	765.0	767.5	770.0	772.5
31	775.0	777.5	780.0	782.5	785.0	787.5	790.0	792.5	795.0	797.5
32	800.0	802.5	805.0	807.5	810.0	812.5	815.0	817.5	820.0	822.5
33	825.0	827.5	830.0	832.5	835.0	837.5	840.0	842.5	845.0	847.5
34	850.0	852.5	855.0	857.5	860.0	862.5	865.0	867.5	870.0	872.5
35	875.0	877.5	880.0	882.5	885.0	887.5	890.0	892.5	895.0	897.5
36	900.0	902.5	905.0	907.5	910.0	912.5	915.0	917.5	920.0	922.5
37	925.0	927.5	930.0	932.5	935.0	937.5	940.0	942.5	945.0	947.5
38	950.0	952.5	955.0	957.5	960.0	962.5	965.0	967.5	970.0	972.5
39	975.0	977.5	980.0	982.5	985.0	987.5	990.0	992.5	995.0	997.5
40	1000.0	1002.5	1005.0	1007.5	1010.0	1012.5	1015.0	1017.5	1020.0	1022.5
41	1025.0	1027.5	1030.0	1032.5	1035.0	1037.5	1040.0	1042.5	1045.0	1047.5
42	1050.0	1052.5	1055.0	1057.5	1060.0	1062.5	1065.0	1067.5	1070.0	1072.5
43	1075.0	1077.5	1080.0	1082.5	1085.0	1087.5	1090.0	1092.5	1095.0	1097.5
44	1100.0	1102.5	1105.0	1107.5	1110.0	1112.5	1115.0	1117.5	1120.0	1122.5
45	1125.0	1127.5	1130.0	1132.5	1135.0	1137.5	1140.0	1142.5	1145.0	1147.5
46	1150.0	1152.5	1155.0	1157.5	1160.0	1162.5	1165.0	1167.5	1170.0	1172.5
47	1175.0	1177.5	1180.0	1182.5	1185.0	1187.5	1190.0	1192.5	1195.0	1197.5
48	1200.0	1202.5	1205.0	1207.5	1210.0	1212.5	1215.0	1217.5	1220.0	1222.5
49	1225.0	1227.5	1230.0	1232.5	1235.0	1237.5	1240.0	1242.5	1245.0	1247.5
50	1250.0	1252.5	1255.0	1257.5	1260.0	1262.5	1265.0	1267.5	1270.0	1272.5

NOTE. — For volumes larger than those given, use figures in the table, moving decimal point one place to the right and add proportional part.

TABLE 39. VOLUME OF 50-FT. SECTIONS IN CUBIC FEET FOR SUM OF END AREAS.—*Continued*

COMPILED BY J. H. HUBER, ASSISTANT ENGINEER, BUFFALO, N.Y.

Sum of End Areas Sq. Ft.	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
50	1250.0	1252.5	1255.0	1257.5	1260.0	1262.5	1265.0	1267.5	1270.0	1272.5
51	1275.0	1277.5	1280.0	1282.5	1285.0	1287.5	1290.0	1292.5	1295.0	1297.5
52	1300.0	1302.5	1305.0	1307.5	1310.0	1312.5	1315.0	1317.5	1320.0	1322.5
53	1325.0	1327.5	1330.0	1332.5	1335.0	1337.5	1340.0	1342.5	1345.0	1347.5
54	1350.0	1352.5	1355.0	1357.5	1360.0	1362.5	1365.0	1367.5	1370.0	1372.5
55	1375.0	1377.5	1380.0	1382.5	1385.0	1387.5	1390.0	1392.5	1395.0	1397.5
56	1400.0	1402.5	1405.0	1407.5	1410.0	1412.5	1415.0	1417.5	1420.0	1422.5
57	1425.0	1427.5	1430.0	1432.5	1435.0	1437.5	1440.0	1442.5	1445.0	1447.5
58	1450.0	1452.5	1455.0	1457.5	1460.0	1462.5	1465.0	1467.5	1470.0	1472.5
59	1475.0	1477.5	1480.0	1482.5	1485.0	1487.5	1490.0	1492.5	1495.0	1497.5
60	1500.0	1502.5	1505.0	1507.5	1510.0	1512.5	1515.0	1517.5	1520.0	1522.5
61	1525.0	1527.5	1530.0	1532.5	1535.0	1537.5	1540.0	1542.5	1545.0	1547.5
62	1550.0	1552.5	1555.0	1557.5	1560.0	1562.5	1565.0	1567.5	1570.0	1572.5
63	1575.0	1577.5	1580.0	1582.5	1585.0	1587.5	1590.0	1592.5	1595.0	1597.5
64	1600.0	1602.5	1605.0	1607.5	1610.0	1612.5	1615.0	1617.5	1620.0	1622.5
65	1625.0	1627.5	1630.0	1632.5	1635.0	1637.5	1640.0	1642.5	1645.0	1647.5
66	1650.0	1652.5	1655.0	1657.5	1660.0	1662.5	1665.0	1667.5	1670.0	1672.5
67	1675.0	1677.5	1680.0	1682.5	1685.0	1687.5	1690.0	1692.5	1695.0	1697.5
68	1700.0	1702.5	1705.0	1707.5	1710.0	1712.5	1715.0	1717.5	1720.0	1722.5
69	1725.0	1727.5	1730.0	1732.5	1735.0	1737.5	1740.0	1742.5	1745.0	1747.5
70	1750.0	1752.5	1755.0	1757.5	1760.0	1762.5	1765.0	1767.5	1770.0	1772.5
71	1775.0	1777.5	1780.0	1782.5	1785.0	1787.5	1790.0	1792.5	1795.0	1797.5
72	1800.0	1802.5	1805.0	1807.5	1810.0	1812.5	1815.0	1817.5	1820.0	1822.5
73	1825.0	1827.5	1830.0	1832.5	1835.0	1837.5	1840.0	1842.5	1845.0	1847.5
74	1850.0	1852.5	1855.0	1857.5	1860.0	1862.5	1865.0	1867.5	1870.0	1872.5
75	1875.0	1877.5	1880.0	1882.5	1885.0	1887.5	1890.0	1892.5	1895.0	1897.5
76	1900.0	1902.5	1905.0	1907.5	1910.0	1912.5	1915.0	1917.5	1920.0	1922.5
77	1925.0	1927.5	1930.0	1932.5	1935.0	1937.5	1940.0	1942.5	1945.0	1947.5
78	1950.0	1952.5	1955.0	1957.5	1960.0	1962.5	1965.0	1967.5	1970.0	1972.5
79	1975.0	1977.5	1980.0	1982.5	1985.0	1987.5	1990.0	1992.5	1995.0	1997.5
80	2000.0	2002.5	2005.0	2007.5	2010.0	2012.5	2015.0	2017.5	2020.0	2022.5
81	2025.0	2027.5	2030.0	2032.5	2035.0	2037.5	2040.0	2042.5	2045.0	2047.5
82	2050.0	2052.5	2055.0	2057.5	2060.0	2062.5	2065.0	2067.5	2070.0	2072.5
83	2075.0	2077.5	2080.0	2082.5	2085.0	2087.5	2090.0	2092.5	2095.0	2097.5
84	2100.0	2102.5	2105.0	2107.5	2110.0	2112.5	2115.0	2117.5	2120.0	2122.5
85	2125.0	2127.5	2130.0	2132.5	2135.0	2137.5	2140.0	2142.5	2145.0	2147.5
86	2150.0	2152.5	2155.0	2157.5	2160.0	2162.5	2165.0	2167.5	2170.0	2172.5
87	2175.0	2177.5	2180.0	2182.5	2185.0	2187.5	2190.0	2192.5	2195.0	2197.5
88	2200.0	2202.5	2205.0	2207.5	2210.0	2212.5	2215.0	2217.5	2220.0	2222.5
89	2225.0	2227.5	2230.0	2232.5	2235.0	2237.5	2240.0	2242.5	2245.0	2247.5
90	2250.0	2252.5	2255.0	2257.5	2260.0	2262.5	2265.0	2267.5	2270.0	2272.5
91	2275.0	2277.5	2280.0	2282.5	2285.0	2287.5	2290.0	2292.5	2295.0	2297.5
92	2300.0	2302.5	2305.0	2307.5	2310.0	2312.5	2315.0	2317.5	2320.0	2322.5
93	2325.0	2327.5	2330.0	2332.5	2335.0	2337.5	2340.0	2342.5	2345.0	2347.5
94	2350.0	2352.5	2355.0	2357.5	2360.0	2362.5	2365.0	2367.5	2370.0	2372.5
95	2375.0	2377.5	2380.0	2382.5	2385.0	2387.5	2390.0	2392.5	2395.0	2397.5
96	2400.0	2402.5	2405.0	2407.5	2410.0	2412.5	2415.0	2417.5	2420.0	2422.5
97	2425.0	2427.5	2430.0	2432.5	2435.0	2437.5	2440.0	2442.5	2445.0	2447.5
98	2450.0	2452.5	2455.0	2457.5	2460.0	2462.5	2465.0	2467.5	2470.0	2472.5
99	2475.0	2477.5	2480.0	2482.5	2485.0	2487.5	2490.0	2492.5	2495.0	2497.5
100	2500.0	2502.5	2505.0	2507.5	2510.0	2512.5	2515.0	2517.5	2520.0	2522.5

OPORTIONAL PART	0.0	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
		2.5	5.0	7.5	10.0	12.5	15.0	17.5	20.0	22.5

Table 40. Cubic Feet and Cubic Yards

0–1350		1350–2700		2700–4050		4050–5400	
Feet	Yds.	Feet	Yds.	Feet	Yds.	Feet	Yds.
27	1	77	51	2,727	101	77	151
54	2	1,404	2	54	2	4,104	2
81	3	31	3	81	3	31	3
108	4	58	4	2,808	4	58	4
35	5	85	5	35	5	85	5
62	6	1,512	6	62	6	4,212	6
89	7	39	7	89	7	39	7
216	8	66	8	2,916	8	66	8
43	9	93	9	43	9	93	9
70	10	1,620	60	70	110	4,320	160
97	1	47	1	97	1	47	1
324	2	74	2	3,024	2	74	2
51	3	1,701	3	51	3	4,401	3
78	4	28	4	78	4	28	4
405	5	55	5	3,105	5	55	5
32	6	82	6	32	6	82	6
59	7	1,809	7	59	7	4,509	7
86	8	36	8	86	8	36	8
513	9	63	9	3,213	9	63	9
40	20	90	70	40	120	90	170
67	1	1,917	1	67	1	4,617	1
94	2	44	2	94	2	44	2
621	3	71	3	3,321	3	71	3
48	4	98	4	48	4	98	4
75	5	2,025	5	75	5	4,725	5
702	6	52	6	3,402	6	52	6
29	7	79	7	29	7	79	7
56	8	2,106	8	56	8	4,806	8
83	9	33	9	83	9	33	9
810	30	60	80	3,510	130	60	180
37	1	87	1	37	1	87	1
64	2	2,214	2	64	2	4,914	2
91	3	41	3	91	3	41	3
918	4	68	4	3,618	4	68	4
45	5	95	5	45	5	95	5
72	6	2,322	6	72	6	5,022	6
99	7	49	7	99	7	49	7
1,026	8	76	8	3,726	8	76	8
53	9	2,403	9	53	9	5,103	9
80	40	30	90	80	140	30	190
1,107	1	57	1	3,807	1	57	1
34	2	84	2	34	2	84	2
61	3	2,511	3	61	3	5,211	3
88	4	38	4	88	4	38	4
1,215	5	65	5	3,915	5	65	5
42	6	92	6	42	6	92	6
69	7	2,619	7	69	7	5,319	7
96	8	46	8	96	8	46	8
1,323	9	73	9	4,023	9	73	9
50	50	2,700	100	50	150	5,400	200

TABLE 40—*Continued*

5400–6750		6750–8100		8100–9450		9450–10,800	
Feet	Yds.	Feet	Yds.	Feet	Yds.	Feet	Yds.
5,427	201	77	251	8,127	301	77	351
54	2	6,804	2	54	2	9,504	2
81	3	31	3	81	3	31	3
5,508	4	58	4	8,208	4	58	4
35	5	85	5	35	5	85	5
62	6	6,912	6	62	6	9,612	6
89	7	39	7	89	7	39	7
5,616	8	66	8	8,316	8	66	8
43	9	93	9	43	9	93	9
70	210	7,020	260	70	310	9,720	360
97	1	47	1	97	1	47	1
5,724	2	74	2	8,424	2	74	2
51	3	7,101	3	51	3	9,801	3
78	4	28	4	78	4	28	4
5,805	5	55	5	8,505	5	55	5
32	6	82	6	32	6	82	6
59	7	7,209	7	59	7	9,909	7
86	8	36	8	86	8	36	8
5,913	9	63	9	8,613	9	63	9
40	220	90	270	40	320	90	370
67	1	7,317	1	67	1	10,017	1
94	2	44	2	94	2	44	2
6,021	3	71	3	8,721	3	71	3
48	4	98	4	48	4	98	4
75	5	7,425	5	75	5	10,125	5
6,102	6	52	6	8,802	6	52	6
29	7	79	7	29	7	79	7
56	8	7,506	8	56	8	10,206	8
83	9	33	9	83	9	33	9
6,210	230	60	280	8,910	330	60	380
37	1	87	1	37	1	87	1
64	2	7,614	2	64	2	10,314	2
91	3	41	3	91	3	41	3
6,318	4	68	4	9,018	4	68	4
45	5	95	5	45	5	95	5
72	6	7,722	6	72	6	10,422	6
99	7	49	7	99	7	49	7
6,426	8	76	8	9,126	8	76	8
53	9	7,803	9	53	9	10,503	9
80	240	30	290	80	340	30	390
6,507	1	57	1	9,207	1	57	1
34	2	84	2	34	2	84	2
61	3	7,911	3	61	3	10,611	3
88	4	38	4	88	4	38	4
6,615	5	65	5	9,315	5	65	5
42	6	92	6	42	6	92	6
69	7	8,019	7	69	7	10,719	7
96	8	46	8	96	8	46	8
6,723	9	73	9	9,423	9	73	9
50	250	8,100	300	50	350	10,800	400

TABLE 40—*Continued*

10,800–12,150		12,150–13,500		13,500–14,850		14,850–16,200	
Feet	Yds.	Feet	Yds.	Feet	Yds.	Feet	Yds.
10,827	401	77	451	13,527	501	177	551
54	2	12,204	2	54	2	14,904	2
81	3	31	3	81	3	31	3
10,908	4	58	4	13,608	4	58	4
35	5	85	5	35	5	85	5
62	6	12,312	6	62	6	15,012	6
89	7	39	7	89	7	39	7
11,016	8	66	8	13,716	8	66	8
43	9	93	9	43	9	93	9
70	410	12,420	460	70	510	15,120	560
97	1	47	1	97	1	47	1
11,124	2	74	2	13,824	2	74	2
51	3	12,501	3	51	3	15,201	3
78	4	28	4	78	4	28	4
11,205	5	55	5	13,905	5	55	5
32	6	82	6	32	6	82	6
59	7	12,609	7	59	7	15,309	7
86	8	36	8	86	8	36	8
11,313	9	63	9	14,013	9	63	9
40	420	90	470	40	520	90	570
67	1	12,717	1	67	1	15,417	1
94	2	44	2	94	2	44	2
11,421	3	71	3	14,121	3	71	3
48	4	98	4	48	4	98	4
75	5	12,825	5	75	5	15,525	5
11,502	6	52	6	14,202	6	52	6
29	7	79	7	29	7	79	7
56	8	12,906	8	56	8	15,606	8
83	9	33	9	83	9	33	9
11,610	430	60	480	14,310	530	60	580
37	1	87	1	37	1	87	1
64	2	13,014	2	64	2	15,714	2
91	3	41	3	91	3	41	3
11,718	4	68	4	14,418	4	68	4
45	5	95	5	45	5	95	5
72	6	13,122	6	72	6	15,822	6
99	7	49	7	99	7	49	7
11,826	8	76	8	14,526	8	76	8
53	9	13,203	9	53	9	15,903	9
80	440	30	490	80	540	30	590
11,907	1	57	1	14,607	1	57	1
34	2	84	2	34	2	84	2
61	3	13,311	3	61	3	16,011	3
88	4	38	4	88	4	38	4
12,015	5	65	5	14,715	5	65	5
42	6	92	6	42	6	92	6
69	7	13,419	7	69	7	16,119	7
96	8	46	8	96	8	46	8
12,123	9	73	9	14,823	9	73	9
50	450	13,500	500	50	550	16,200	600

TABLE 40—*Continued*

16,200–17,550		17,550–18,900		18,900–20,250		20,250–21,600	
Feet	Yds.	Feet	Yds.	Feet	Yds.	Feet	Yds.
16,227	601	77	651	18,927	701	77	751
54	2	17,604	2	54	2	20,304	2
81	3	31	3	81	3	31	3
16,308	4	58	4	19,008	4	58	4
35	5	85	5	35	5	85	5
62	6	17,712	6	62	6	20,412	6
89	7	39	7	89	7	39	7
16,416	8	66	8	19,116	8	66	8
43	9	93	9	43	9	93	9
70	610	17,820	660	70	710	20,520	760
97	1	47	1	97	1	47	1
16,524	2	74	2	19,224	2	74	2
51	3	17,901	3	51	3	20,601	3
78	4	28	4	78	4	28	4
16,605	5	55	5	19,305	5	55	5
32	6	82	6	32	6	82	6
59	7	18,009	7	59	7	20,709	7
86	8	36	8	86	8	36	8
16,713	9	63	9	19,413	9	63	9
40	620	90	670	40	720	90	770
67	1	18,117	1	67	1	20,817	1
94	2	44	2	94	2	44	2
16,821	3	71	3	19,521	3	71	3
48	4	98	4	48	4	98	4
75	5	18,225	5	75	5	20,925	5
16,902	6	52	6	19,602	6	52	6
29	7	79	7	29	7	79	7
56	8	18,306	8	56	8	21,006	8
83	9	33	9	83	9	33	9
17,010	630	60	680	19,710	730	60	780
37	1	87	1	37	1	87	1
64	2	18,414	2	64	2	21,114	2
91	3	41	3	91	3	41	3
17,118	4	68	4	19,818	4	68	4
45	5	95	5	45	5	95	5
72	6	18,522	6	72	6	21,222	6
99	7	49	7	99	7	49	7
17,226	8	76	8	19,926	8	76	8
53	9	18,603	9	53	9	21,303	9
80	640	30	690	80	740	30	790
17,307	1	57	1	20,007	1	57	1
34	2	84	2	34	2	84	2
61	3	18,711	3	61	3	21,411	3
88	4	38	4	88	4	38	4
17,415	5	65	5	20,115	5	65	5
42	6	92	6	42	6	92	6
69	7	18,819	7	69	7	21,519	7
96	8	46	8	96	8	46	8
17,523	9	73	9	20,223	9	73	9
50	650	18,900	700	50	750	21,600	800

TABLE 40—*Continued*

21,600–22,950		22,950–24,300		24,300–25,650		25,650–27,000	
Feet	Yds.	Feet	Yds.	Feet	Yds.	Feet	Yds.
21,627	801	77	851	24,327	901	77	951
54	2	23,004	2	54	2	25,704	2
81	3	31	3	81	3	31	3
21,708	4	58	4	24,408	4	58	4
35	5	85	5	35	5	85	5
62	6	23,112	6	62	6	25,812	6
89	7	39	7	89	7	39	7
21,816	8	66	8	24,516	8	66	8
43	9	93	9	43	9	93	9
70	810	23,220	860	70	910	25,920	960
97	1	47	1	97	1	47	1
21,924	2	74	2	24,624	2	74	2
51	3	23,301	3	51	3	26,001	3
78	4	28	4	78	4	28	4
22,005	5	55	5	24,705	5	55	5
32	6	82	6	32	6	82	6
59	7	23,409	7	59	7	26,109	7
86	8	36	8	86	8	36	8
22,113	9	63	9	24,813	9	63	9
40	820	90	870	40	920	90	970
67	1	23,517	1	67	1	26,217	1
94	2	44	2	94	2	44	2
22,221	3	71	3	24,921	3	71	3
48	4	98	4	48	4	98	4
75	5	23,625	5	75	5	26,325	5
22,302	6	52	6	25,002	6	52	6
29	7	79	7	29	7	79	7
56	8	23,706	8	56	8	26,406	8
83	9	33	9	83	9	33	9
22,410	830	60	880	25,110	930	60	980
37	1	87	1	37	1	87	1
64	2	23,814	2	64	2	26,514	2
91	3	41	3	91	3	41	3
22,518	4	68	4	25,218	4	68	4
45	5	95	5	45	5	95	5
72	6	23,922	6	72	6	26,622	6
99	7	49	7	99	7	49	7
22,626	8	76	8	25,326	8	76	8
53	9	24,003	9	53	9	26,703	9
80	840	30	890	80	940	30	990
22,707	1	57	1	25,407	1	57	1
34	2	84	2	34	2	84	2
61	3	24,111	3	61	3	26,811	3
88	4	38	4	88	4	38	4
22,815	5	65	5	25,515	5	65	5
42	6	92	6	42	6	92	6
69	7	24,219	7	69	7	26,919	7
96	8	46	8	96	8	46	8
22,923	9	73	9	25,623	9	73	9
50	850	24,300	900	50	950	27,000	1000

TABLE 40—*Continued*

27,000–28,350		28,350–29,700		29,700–31,050		31,050–32,400	
Feet	Yds.	Feet	Yds.	Feet	Yds.	Feet	Yds.
27,027	1001	77	1051	29,727	1101	77	1151
54	2	28,404	2	54	2	31,104	2
81	3	31	3	81	3	31	3
27,108	4	58	4	29,808	4	58	4
35	5	85	5	35	5	85	5
62	6	28,512	6	62	6	31,212	6
89	7	39	7	89	7	39	7
27,216	8	66	8	29,916	8	66	8
43	9	93	9	43	9	93	9
70	1010	28,620	1060	70	1110	31,320	1160
97	1	47	1	97	1	47	1
27,324	2	74	2	30,024	2	74	2
51	3	28,701	3	51	3	31,401	3
78	4	28	4	78	4	28	4
27,405	5	55	5	30,105	5	55	5
32	6	82	6	32	6	82	6
59	7	28,809	7	59	7	31,509	7
86	8	36	8	86	8	36	8
27,513	9	63	9	30,213	9	63	9
40	1020	90	1070	40	1120	90	1170
67	1	28,917	1	67	1	31,617	1
94	2	44	4	94	2	44	2
27,621	3	71	3	30,321	3	71	3
48	4	98	4	48	4	98	4
75	5	29,025	5	75	5	31,725	5
27,702	6	52	6	30,402	6	52	6
29	7	79	7	29	7	79	7
56	8	29,106	8	56	8	31,806	8
83	9	33	9	83	9	33	9
27,810	1030	60	1080	30,510	1130	60	1180
37	1	87	1	37	1	87	1
64	2	29,214	2	64	2	31,914	2
91	3	41	3	91	3	41	3
27,918	4	68	4	30,618	4	68	4
45	5	95	5	45	5	95	5
72	6	29,322	6	72	6	32,022	6
99	7	49	7	99	7	49	7
28,026	8	76	8	30,726	8	76	8
53	9	29,403	9	53	9	32,103	9
80	1040	30	1090	80	1140	30	1190
28,107	1	57	1	30,807	1	57	1
34	2	84	2	34	2	84	2
61	3	29,511	3	61	3	32,211	3
88	4	38	4	88	4	38	4
28,215	5	65	5	30,915	5	65	5
42	6	92	6	42	6	92	6
69	7	29,619	7	69	7	32,319	7
96	8	46	8	96	8	46	8
28,323	9	73	9	31,023	9	73	9
50	1050	29,700	1100	50	1150	32,400	1200

TABLE 40—*Continued*

32,400–33,750		33,750–35,100		35,100–36,450		36,450–37,800	
Feet	Yds.	Feet	Yds.	Feet	Yds.	Feet	Yds.
32,427	1201	77	1251	35,127	1301	77	1351
54	2	33,804	2	54	2	36,504	2
81	3	31	3	81	3	31	3
32,508	4	58	4	35,208	4	58	4
35	5	85	5	35	5	85	5
62	6	33,912	6	62	6	36,612	6
89	7	39	7	89	7	39	7
32,616	8	66	8	35,316	8	66	8
43	9	93	9	43	9	93	9
70	1210	34,020	1260	70	1310	36,720	1360
97	1	47	1	97	1	47	1
32,724	2	74	2	35,424	2	74	2
51	3	34,101	3	51	3	36,801	3
78	4	28	4	78	4	28	4
32,805	5	55	5	35,505	5	55	5
32	6	82	6	32	6	82	6
59	7	34,209	7	59	7	36,909	7
86	8	36	8	86	8	36	8
32,913	9	63	9	35,613	9	63	9
40	1220	90	1270	40	1320	90	1370
67	1	34,317	1	67	1	37,017	1
94	2	44	2	94	2	44	2
33,021	3	71	3	35,721	3	71	3
48	4	98	4	48	4	98	4
75	5	34,425	5	75	5	37,125	5
33,102	6	52	6	35,802	6	52	6
29	7	79	7	29	7	79	7
56	8	34,506	8	56	8	37,206	8
83	9	33	9	83	9	33	9
33,210	1230	60	1280	35,910	1330	60	1380
37	1	87	1	37	1	87	1
64	2	34,614	2	64	2	37,314	2
91	3	41	3	91	3	41	3
33,318	4	68	4	36,018	4	68	4
45	5	95	5	45	5	95	5
72	6	34,722	6	72	6	37,422	6
99	7	49	7	99	7	49	7
33,426	8	76	8	36,126	8	76	8
53	9	34,803	9	53	9	37,503	9
80	1240	30	1290	80	1340	30	1390
33,507	1	57	1	36,207	1	57	1
34	2	84	2	34	2	84	2
61	3	34,911	3	61	3	37,611	3
88	4	38	4	88	4	38	4
33,615	5	65	5	36,315	5	65	5
42	6	92	6	42	6	92	6
69	7	35,019	7	69	7	37,719	7
96	8	46	8	96	8	46	8
33,723	9	73	9	36,423	9	73	9
50	1250	35,100	1300	50	1350	37,800	1400

TABLE 40—*Concluded*

37,800–39,150		39,150–40,500		40,500–41,850		41,850–43,200	
Feet	Yds.	Feet	Yds.	Feet	Yds.	Feet	Yds.
37,827	1401	77	1451	40,527	1501	77	1551
54	2	39,204	2	54	2	41,904	2
81	3	31	3	81	3	31	3
37,908	4	58	4	40,608	4	58	4
35	5	85	5	35	5	85	5
62	6	39,312	6	62	6	42,012	6
89	7	39	7	89	7	39	7
38,016	8	66	8	40,716	8	66	8
43	9	93	9	43	9	93	9
70	1410	39,420	1460	70	1510	42,120	1560
97	1	47	1	97	1	47	1
38,124	2	74	2	40,824	2	74	2
51	3	39,501	3	51	3	42,201	3
78	4	28	4	78	4	28	4
38,205	5	55	5	40,905	5	55	5
32	6	82	6	32	6	82	6
59	7	39,609	7	59	7	42,309	7
86	8	36	8	86	8	36	8
38,313	9	63	9	41,013	9	63	9
40	1420	90	1470	40	1520	90	1570
67	1	39,717	1	67	1	42,417	1
94	2	44	2	94	2	44	2
38,421	3	71	3	41,121	3	71	3
48	4	98	4	48	4	98	4
75	5	39,825	5	75	5	42,525	5
38,502	6	52	6	41,202	6	52	6
29	7	79	7	29	7	79	7
56	8	39,906	8	56	8	42,606	8
83	9	33	9	83	9	33	9
38,610	1430	60	1480	41,310	1530	60	1580
37	1	87	1	37	1	87	1
64	2	40,014	2	64	2	42,714	2
91	3	41	3	91	3	41	3
38,718	4	68	4	41,418	4	68	4
45	5	95	5	45	5	95	5
72	6	40,122	6	72	6	42,822	6
99	7	49	7	99	7	49	7
38,826	8	76	8	41,526	8	76	8
53	9	40,203	9	53	9	42,903	9
80	1440	30	1490	80	1540	30	1590
38,907	1	57	1	41,607	1	57	1
34	2	84	2	34	2	84	2
61	3	40,311	3	61	3	43,011	3
88	4	38	4	88	4	38	4
39,015	5	65	5	41,715	5	65	5
42	6	92	6	42	6	92	6
69	7	40,419	7	69	7	43,119	7
96	8	46	8	96	8	46	8
39,123	9	73	9	41,823	9	73	9
50	1450	40,500	1500	50	1550	43,200	1600

Table 41. New York State Department of Highways. Earthwork Computation Tables

Distance Horizontal   Sum of Areas Vertical   Quantities in Cubic Yards

2	3	4	5	6	7	8	9	10	11	12	13	14	D'uble Areas
0.0	0.1	0.1	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.3	1.0
0.0	0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.2	0.3	0.3	0.3	2
0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.2	0.3	0.3	0.3	0.3	0.4	4
0.1	0.1	0.1	0.1	0.2	0.2	0.2	0.3	0.3	0.3	0.4	0.4	0.4	6
0.1	0.1	0.1	0.2	0.2	0.2	0.3	0.3	0.3	0.4	0.4	0.4	0.5	8
0.1	0.1	0.1	0.2	0.2	0.3	0.3	0.3	0.4	0.4	0.4	0.5	0.5	2.0
0.1	0.1	0.2	0.2	0.2	0.3	0.3	0.4	0.4	0.4	0.5	0.5	0.6	2
0.1	0.1	0.2	0.2	0.3	0.3	0.4	0.4	0.4	0.5	0.5	0.6	0.6	4
0.1	0.1	0.2	0.2	0.3	0.3	0.4	0.4	0.5	0.5	0.6	0.6	0.7	6
0.1	0.2	0.2	0.3	0.3	0.4	0.4	0.5	0.5	0.6	0.6	0.7	0.7	8
0.1	0.2	0.2	0.3	0.3	0.4	0.4	0.5	0.6	0.6	0.7	0.7	0.8	3.0
0.1	0.2	0.2	0.3	0.4	0.4	0.5	0.5	0.6	0.7	0.7	0.8	0.8	2
0.1	0.2	0.3	0.3	0.4	0.4	0.5	0.6	0.6	0.7	0.8	0.8	0.9	4
0.1	0.2	0.3	0.3	0.4	0.5	0.5	0.6	0.7	0.7	0.8	0.9	0.9	6
0.1	0.2	0.3	0.4	0.4	0.5	0.6	0.6	0.7	0.8	0.8	0.9	1.0	8
0.1	0.2	0.3	0.4	0.4	0.5	0.6	0.7	0.7	0.8	0.9	1.0	1.0	4.0
0.2	0.2	0.3	0.4	0.5	0.5	0.6	0.7	0.8	0.9	0.9	1.0	1.1	2
0.2	0.2	0.3	0.4	0.5	0.6	0.7	0.7	0.8	0.9	1.0	1.1	1.1	4
0.2	0.3	0.3	0.4	0.5	0.6	0.7	0.8	0.9	0.9	1.0	1.1	1.2	6
0.2	0.3	0.4	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.2	8
0.2	0.3	0.4	0.5	0.6	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	5.0
0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.3	2
0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	4
0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.5	6
0.2	0.3	0.4	0.5	0.6	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.5	8
0.2	0.3	0.4	0.6	0.7	0.8	0.9	1.0	1.1	1.2	1.3	1.4	1.6	6.0
0.2	0.3	0.5	0.6	0.7	0.8	0.9	1.1	1.1	1.3	1.4	1.5	1.6	2
0.2	0.4	0.5	0.6	0.7	0.8	0.9	1.1	1.2	1.3	1.4	1.5	1.7	4
0.2	0.4	0.5	0.6	0.7	0.9	1.0	1.1	1.2	1.3	1.5	1.6	1.7	6
0.3	0.4	0.5	0.6	0.7	0.9	1.0	1.1	1.3	1.4	1.5	1.6	1.8	8
0.3	0.4	0.5	0.6	0.8	0.9	1.0	1.2	1.3	1.4	1.6	1.7	1.8	7.0
0.3	0.4	0.5	0.7	0.8	0.9	1.1	1.2	1.3	1.5	1.6	1.7	1.9	2
0.3	0.4	0.5	0.7	0.8	1.0	1.1	1.2	1.4	1.5	1.6	1.8	1.9	4
0.3	0.4	0.6	0.7	0.8	1.0	1.1	1.3	1.4	1.5	1.7	1.8	2.0	6
0.3	0.4	0.6	0.7	0.9	1.0	1.2	1.3	1.4	1.6	1.7	1.9	2.0	8
0.3	0.4	0.6	0.7	0.9	1.0	1.2	1.3	1.5	1.6	1.8	1.9	2.1	8.0
0.3	0.5	0.6	0.8	0.9	1.1	1.2	1.4	1.5	1.7	1.8	2.0	2.1	2
0.3	0.5	0.6	0.8	0.9	1.1	1.2	1.4	1.6	1.7	1.9	2.0	2.2	4
0.3	0.5	0.6	0.8	1.0	1.1	1.3	1.4	1.6	1.7	1.9	2.1	2.2	6
0.3	0.5	0.7	0.8	1.0	1.1	1.3	1.5	1.6	1.8	2.0	2.1	2.3	8
0.3	0.5	0.7	0.9	1.0	1.2	1.3	1.5	1.7	1.8	2.0	2.2	2.3	9.0
0.3	0.5	0.7	0.9	1.0	1.2	1.4	1.5	1.7	1.9	2.0	2.2	2.4	2
0.3	0.5	0.7	0.9	1.0	1.2	1.4	1.6	1.7	1.9	2.1	2.3	2.4	4
0.4	0.5	0.7	0.9	1.1	1.2	1.4	1.6	1.8	2.0	2.1	2.3	2.5	6
0.4	0.5	0.7	0.9	1.1	1.3	1.5	1.6	1.8	2.0	2.2	2.4	2.5	8
0.4	0.6	0.7	0.9	1.1	1.3	1.5	1.7	1.9	2.0	2.2	2.4	2.6	10.0
0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	1.9	2.1	2.3	2.5	2.7	5
0.4	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.4	2.6	2.9	11.0
0.4	0.6	0.9	1.1	1.3	1.5	1.7	1.9	2.1	2.3	2.5	2.8	3.0	5
0.4	0.7	0.9	1.1	1.3	1.6	1.8	2.0	2.2	2.4	2.7	2.9	3.1	12.0
0.5	0.7	0.9	1.2	1.4	1.6	1.9	2.1	2.3	2.5	2.8	3.0	3.2	5
0.5	0.7	1.0	1.2	1.5	1.7	2.0	2.2	2.4	2.6	2.9	3.1	3.4	13.0
0.5	0.7	1.0	1.3	1.5	1.8	2.0	2.3	2.5	2.7	3.0	3.3	3.5	5
0.5	0.8	1.0	1.3	1.6	1.8	2.1	2.3	2.6	2.8	3.1	3.4	3.6	14.0

TABLE 41—*Continued*

DISTANCE HORIZONTAL SUM OF AREAS VERTICAL QUANTITIES IN CUBIC YARDS

15	16	17	18	19	20	21	22	23	24	25	26	27	D'uble Areas
0.3	0.3	0.3	0.3	0.4	0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.5	1.0
0.3	0.4	0.4	0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.6	0.6	0.6	2
0.4	0.4	0.4	0.5	0.5	0.5	0.5	0.6	0.6	0.6	0.6	0.7	0.7	4
0.4	0.5	0.5	0.5	0.6	0.6	0.6	0.7	0.7	0.7	0.7	0.8	0.8	6
0.5	0.5	0.6	0.6	0.6	0.7	0.7	0.7	0.8	0.8	0.8	0.9	0.9	8
0.6	0.6	0.6	0.7	0.7	0.7	0.8	0.8	0.9	0.9	0.9	1.0	1.0	2.0
0.6	0.7	0.7	0.7	0.8	0.8	0.9	0.9	0.9	1.0	1.0	1.1	1.1	2
0.7	0.7	0.8	0.8	0.8	0.9	0.9	1.0	1.0	1.1	1.1	1.2	1.2	4
0.7	0.8	0.8	0.9	0.9	1.0	1.0	1.1	1.1	1.2	1.2	1.3	1.3	6
0.8	0.8	0.9	1.0	1.0	1.0	1.1	1.1	1.2	1.2	1.3	1.4	1.4	8
0.8	0.9	0.9	1.0	1.1	1.1	1.2	1.2	1.3	1.3	1.4	1.4	1.5	3.0
0.9	0.9	1.0	1.1	1.1	1.2	1.2	1.3	1.4	1.4	1.5	1.5	1.6	2
0.9	1.0	1.1	1.1	1.2	1.3	1.3	1.4	1.4	1.5	1.6	1.6	1.7	4
1.0	1.1	1.1	1.2	1.3	1.3	1.4	1.5	1.5	1.6	1.7	1.7	1.8	6
1.1	1.1	1.2	1.3	1.3	1.4	1.5	1.5	1.6	1.7	1.8	1.8	1.9	8
1.1	1.2	1.3	1.3	1.4	1.5	1.6	1.6	1.7	1.8	1.9	1.9	2.0	4.0
1.2	1.2	1.3	1.4	1.5	1.6	1.6	1.7	1.8	1.9	1.9	2.0	2.1	2
1.2	1.3	1.4	1.5	1.5	1.6	1.7	1.8	1.9	2.0	2.0	2.1	2.2	4
1.3	1.4	1.4	1.5	1.6	1.7	1.8	1.9	2.0	2.0	2.1	2.2	2.3	6
1.3	1.4	1.5	1.6	1.7	1.8	1.8	2.0	2.0	2.1	2.2	2.3	2.4	8
1.4	1.5	1.6	1.7	1.8	1.9	1.9	2.0	2.1	2.2	2.3	2.4	2.5	5.0
1.4	1.5	1.6	1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2
1.5	1.6	1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2.7	4
1.6	1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.5	2.6	2.7	2.8	6
1.6	1.7	1.8	2.0	2.0	2.2	2.3	2.4	2.5	2.6	2.7	2.8	2.9	8
1.7	1.8	1.9	2.0	2.1	2.2	2.3	2.4	2.6	2.7	2.8	2.9	3.0	6.0
1.7	1.8	1.9	2.1	2.2	2.3	2.4	2.5	2.6	2.8	2.9	3.0	3.1	2
1.8	1.9	2.0	2.1	2.2	2.4	2.5	2.6	2.7	2.8	3.0	3.1	3.2	4
1.8	2.0	2.1	2.2	2.3	2.5	2.6	2.7	2.8	2.9	3.1	3.2	3.3	6
1.9	2.0	2.1	2.3	2.4	2.5	2.6	2.8	2.9	3.0	3.2	3.3	3.4	8
1.9	2.1	2.2	2.3	2.5	2.6	2.7	2.9	3.0	3.1	3.2	3.4	3.5	7.0
2.0	2.1	2.3	2.4	2.5	2.7	2.8	2.9	3.1	3.2	3.3	3.5	3.6	2
2.1	2.2	2.3	2.5	2.6	2.7	2.9	3.0	3.1	3.3	3.4	3.6	3.7	4
2.1	2.3	2.4	2.5	2.7	2.8	3.0	3.1	3.2	3.4	3.5	3.7	3.8	6
2.2	2.3	2.5	2.6	2.7	2.9	3.0	3.2	3.3	3.5	3.6	3.8	3.9	8
2.2	2.4	2.5	2.7	2.8	3.0	3.1	3.3	3.4	3.6	3.7	3.9	4.0	8.0
2.3	2.4	2.6	2.7	2.9	3.0	3.2	3.3	3.5	3.6	3.8	4.0	4.1	2
2.3	2.5	2.6	2.8	2.9	3.1	3.3	3.4	3.6	3.7	3.9	4.1	4.2	4
2.4	2.5	2.7	2.9	3.0	3.2	3.3	3.5	3.7	3.8	4.0	4.1	4.3	6
2.4	2.6	2.8	2.9	3.1	3.3	3.4	3.6	3.8	3.9	4.1	4.2	4.4	8
2.5	2.7	2.8	3.0	3.2	3.3	3.5	3.7	3.8	4.0	4.2	4.3	4.5	9.0
2.6	2.7	2.9	3.1	3.2	3.4	3.6	3.8	3.9	4.1	4.3	4.4	4.6	2
2.6	2.8	3.0	3.1	3.3	3.5	3.7	3.8	4.0	4.2	4.4	4.5	4.7	4
2.7	2.8	3.0	3.2	3.4	3.6	3.7	3.9	4.1	4.3	4.5	4.6	4.8	6
2.7	2.9	3.1	3.3	3.4	3.6	3.8	4.0	4.2	4.4	4.5	4.7	4.9	8
2.8	3.0	3.1	3.3	3.5	3.7	3.9	4.1	4.2	4.4	4.6	4.8	5.0	100
2.9	3.1	3.3	3.5	3.7	3.9	4.1	4.3	4.5	4.6	4.9	5.0	5.3	5
3.1	3.3	3.5	3.7	3.9	4.1	4.3	4.5	4.7	4.9	5.1	5.3	5.5	11.0
3.2	3.4	3.6	3.8	4.0	4.3	4.5	4.7	4.9	5.1	5.3	5.5	5.7	5
3.3	3.6	3.8	4.0	4.2	4.5	4.7	4.9	5.1	5.3	5.5	5.8	6.0	12.0
3.5	3.7	3.9	4.2	4.4	4.6	4.9	5.1	5.3	5.5	5.8	6.0	6.2	5
3.6	3.8	4.1	4.3	4.6	4.8	5.0	5.3	5.5	5.8	6.0	6.3	6.5	13.0
3.7	4.0	4.2	4.5	4.8	5.0	5.2	5.5	5.8	6.0	6.3	6.5	6.7	5
3.9	4.1	4.4	4.7	4.9	5.2	5.4	5.7	6.0	6.2	6.5	6.7	7.0	14.0

TABLE 41—*Continued*

DISTANCE HORIZONTAL SUM OF AREAS VERTICAL QUANTITIES IN CUBIC YARDS

28	29	30	31	32	33	34	35	36	37	38	39	40	D'uble Areas
0.5	0.5	0.6	0.6	0.6	0.6	0.6	0.7	0.7	0.7	0.7	0.7	0.7	1.0
0.6	0.6	0.7	0.7	0.7	0.7	0.8	0.8	0.8	0.8	0.9	0.9	0.9	2
0.7	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9	1.0	1.0	1.0	1.0	4
0.8	0.9	0.9	0.9	1.0	1.0	1.0	1.0	1.1	1.1	1.1	1.2	1.2	6
0.9	1.0	1.0	1.0	1.1	1.1	1.2	1.2	1.2	1.2	1.3	1.3	1.3	8
1.0	1.1	1.1	1.2	1.2	1.2	1.3	1.3	1.3	1.4	1.4	1.5	1.5	2.0
1.1	1.2	1.2	1.3	1.3	1.3	1.4	1.4	1.5	1.5	1.6	1.6	1.6	2
1.2	1.3	1.3	1.4	1.4	1.5	1.5	1.6	1.6	1.7	1.7	1.7	1.8	4
1.4	1.4	1.4	1.5	1.5	1.6	1.6	1.7	1.7	1.8	1.8	1.9	1.9	6
1.5	1.5	1.6	1.6	1.7	1.7	1.8	1.8	1.9	1.9	2.0	2.0	2.1	8
1.6	1.6	1.7	1.7	1.8	1.8	1.9	1.9	2.0	2.1	2.1	2.2	2.2	3.0
1.7	1.7	1.8	1.8	1.9	2.0	2.0	2.1	2.1	2.2	2.3	2.3	2.4	2
1.8	1.8	1.9	2.0	2.0	2.1	2.1	2.2	2.3	2.3	2.4	2.5	2.5	4
1.9	1.9	2.0	2.1	2.1	2.2	2.3	2.3	2.4	2.5	2.5	2.6	2.7	6
2.0	2.0	2.1	2.2	2.3	2.3	2.4	2.5	2.5	2.6	2.7	2.8	2.8	8
2.1	2.2	2.2	2.3	2.4	2.5	2.5	2.6	2.7	2.7	2.8	2.9	3.0	4.0
2.2	2.3	2.3	2.4	2.5	2.6	2.6	2.7	2.8	2.9	3.0	3.0	3.1	2
2.3	2.4	2.4	2.5	2.6	2.7	2.8	2.9	2.9	3.0	3.1	3.2	3.3	4
2.4	2.5	2.6	2.6	2.7	2.8	2.9	3.0	3.1	3.2	3.2	3.3	3.4	6
2.5	2.6	2.7	2.8	2.8	2.9	3.0	3.1	3.2	3.3	3.4	3.5	3.6	8
2.6	2.7	2.8	2.9	3.0	3.1	3.1	3.2	3.3	3.4	3.5	3.6	3.7	5.0
2.7	2.8	2.9	3.0	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	2
2.8	2.9	3.0	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	4.0	4
2.9	3.0	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9	4.1	4.2	6
3.0	3.1	3.2	3.3	3.4	3.6	3.7	3.8	3.9	4.0	4.1	4.2	4.3	8
3.1	3.2	3.3	3.5	3.6	3.7	3.8	3.9	4.0	4.1	4.2	4.3	4.5	6.0
3.2	3.3	3.5	3.6	3.7	3.8	3.9	4.0	4.1	4.3	4.4	4.5	4.6	2
3.3	3.4	3.6	3.7	3.8	3.9	4.0	4.2	4.3	4.4	4.5	4.6	4.7	4
3.4	3.5	3.7	3.8	3.9	4.0	4.2	4.3	4.4	4.5	4.7	4.8	4.9	6
3.5	3.7	3.8	3.9	4.0	4.2	4.3	4.4	4.5	4.7	4.8	4.9	5.0	8
3.6	3.8	3.9	4.0	4.2	4.3	4.4	4.5	4.7	4.8	4.9	5.1	5.2	7.0
3.7	3.9	4.0	4.1	4.3	4.4	4.5	4.7	4.8	4.9	5.1	5.2	5.3	2
3.8	4.0	4.1	4.3	4.4	4.5	4.7	4.8	4.9	5.1	5.2	5.4	5.5	4
3.9	4.1	4.2	4.4	4.5	4.7	4.8	4.9	5.1	5.2	5.4	5.5	5.6	6
4.0	4.2	4.3	4.5	4.6	4.8	4.9	5.1	5.2	5.4	5.5	5.6	5.8	8
4.2	4.3	4.4	4.6	4.7	4.9	5.0	5.2	5.3	5.5	5.6	5.8	5.9	8.0
4.3	4.4	4.6	4.7	4.9	5.0	5.2	5.3	5.5	5.6	5.8	5.9	6.1	2
4.4	4.5	4.7	4.8	5.0	5.1	5.3	5.5	5.6	5.8	5.9	6.1	6.2	4
4.5	4.6	4.8	4.9	5.1	5.3	5.4	5.6	5.7	5.9	6.1	6.2	6.4	6
4.6	4.7	4.9	5.1	5.2	5.4	5.5	5.7	5.9	6.0	6.2	6.4	6.5	8
4.7	4.8	5.0	5.2	5.3	5.5	5.7	5.8	6.0	6.2	6.3	6.5	6.7	9.0
4.8	4.9	5.1	5.3	5.5	5.6	5.8	6.0	6.1	6.3	6.5	6.7	6.8	2
4.9	5.1	5.2	5.4	5.6	5.8	5.9	6.1	6.3	6.5	6.6	6.8	7.0	4
5.0	5.2	5.3	5.5	5.7	5.9	6.1	6.2	6.4	6.6	6.8	6.9	7.1	6
5.1	5.3	5.5	5.6	5.8	6.0	6.2	6.3	6.5	6.7	6.9	7.1	7.3	8
5.2	5.4	5.6	5.8	5.9	6.1	6.3	6.5	6.7	6.9	7.0	7.2	7.4	10.0
5.4	5.6	5.8	6.0	6.2	6.4	6.6	6.8	7.0	7.2	7.4	7.6	7.8	5
5.7	5.9	6.1	6.3	6.5	6.7	6.9	7.1	7.3	7.5	7.8	7.9	8.2	11.0
6.0	6.2	6.4	6.6	6.8	7.0	7.2	7.5	7.7	7.9	8.1	8.3	8.5	5
6.2	6.4	6.7	7.0	7.1	7.3	7.6	7.8	8.0	8.2	8.5	8.7	8.9	12.0
6.5	6.7	7.0	7.2	7.4	7.7	7.9	8.1	8.3	8.6	8.8	9.0	9.3	5
6.7	7.0	7.2	7.5	7.7	8.0	8.2	8.4	8.7	8.9	9.2	9.4	9.6	13.0
7.0	7.3	7.5	7.8	8.0	8.3	8.5	8.8	9.0	9.3	9.5	9.8	10.0	5
7.2	7.5	7.8	8.0	8.3	8.6	8.8	9.1	9.3	9.6	9.8	10.1	10.4	14.0

TABLE 41—*Continued*

DISTANCE HORIZONTAL SUM OF AREAS VERTICAL QUANTITIES IN CUBIC YARDS

41	42	43	44	45	46	47	48	49	50	75	100		D'uble Areas
0.8	0.8	0.8	0.8	0.8	0.9	0.9	0.9	0.9	0.9	1.4	1.9		1.0
0.9	0.9	1.0	1.0	1.0	1.0	1.0	1.1	1.1	1.1	1.6	2.2		2
1.1	1.1	1.1	1.1	1.2	1.2	1.2	1.2	1.3	1.3	1.9	2.6		4
1.2	1.2	1.3	1.3	1.3	1.4	1.4	1.4	1.5	1.5	2.2	3.0		6
1.4	1.4	1.4	1.5	1.5	1.5	1.6	1.6	1.6	1.7	2.5	3.3		8
1.5	1.6	1.6	1.6	1.7	1.7	1.7	1.8	1.8	1.8	2.8	3.7		2.0
1.7	1.7	1.8	1.8	1.8	1.9	1.9	2.0	2.0	2.0	3.1	4.1		2
1.8	1.9	1.9	2.0	2.0	2.0	2.1	2.1	2.2	2.2	3.3	4.4		4
2.0	2.0	2.1	2.1	2.2	2.2	2.3	2.3	2.4	2.4	3.6	4.8		6
2.1	2.2	2.2	2.3	2.3	2.4	2.4	2.5	2.5	2.6	3.9	5.2		8
2.3	2.3	2.4	2.4	2.5	2.6	2.6	2.7	2.7	2.8	4.2	5.6		3.0
2.4	2.5	2.6	2.6	2.7	2.7	2.8	2.9	2.9	3.0	4.4	5.9		2
2.6	2.6	2.7	2.8	2.8	2.9	3.0	3.0	3.1	3.2	4.7	6.3		4
2.7	2.8	2.9	2.9	3.0	3.1	3.1	3.2	3.3	3.3	5.0	6.7		6
2.9	3.0	3.0	3.1	3.2	3.2	3.3	3.4	3.5	3.5	5.3	7.0		8
3.0	3.1	3.2	3.3	3.3	3.4	3.5	3.6	3.6	3.7	5.6	7.4		4.0
3.2	3.3	3.4	3.4	3.5	3.6	3.7	3.7	3.8	3.9	5.9	7.9		2
3.3	3.4	3.5	3.6	3.7	3.8	3.8	3.9	4.0	4.1	6.1	8.2		4
3.5	3.6	3.7	3.8	3.8	3.9	4.0	4.1	4.2	4.3	6.4	8.5		6
3.6	3.7	3.8	3.9	4.0	4.1	4.2	4.3	4.4	4.5	6.7	8.9		8
3.8	3.9	4.0	4.1	4.2	4.3	4.4	4.5	4.5	4.6	7.0	9.3		5.0
4.0	4.1	4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.8	7.2	9.7		2
4.1	4.2	4.3	4.4	4.5	4.6	4.7	4.8	4.9	5.0	7.5	10.0		4
4.3	4.4	4.5	4.6	4.7	4.8	4.9	5.0	5.1	5.2	7.8	0.4		6
4.4	4.5	4.6	4.7	4.8	4.9	5.0	5.1	5.2	5.4	8.1	0.8		8
4.6	4.7	4.8	4.9	5.0	5.1	5.2	5.3	5.4	5.6	8.3	1.1		6.0
4.7	4.8	4.9	5.0	5.2	5.3	5.4	5.5	5.6	5.7	8.6	1.5		2
4.9	5.0	5.1	5.2	5.3	5.5	5.6	5.7	5.8	5.9	8.9	1.8		4
5.0	5.1	5.2	5.4	5.5	5.6	5.7	5.9	6.0	6.1	9.2	2.2		6
5.2	5.3	5.4	5.5	5.7	5.8	5.9	6.0	6.2	6.3	9.5	2.6		8
5.3	5.4	5.6	5.7	5.8	5.9	6.1	6.2	6.3	6.5	9.7	3.0		7.0
5.5	5.6	5.7	5.8	6.0	6.1	6.3	6.4	6.5	6.7	10.0	3.4		2
5.6	5.7	5.9	6.0	6.2	6.3	6.4	6.6	6.7	6.8	0.3	3.7		4
5.8	5.9	6.0	6.2	6.3	6.5	6.6	6.7	6.9	7.0	0.6	4.1		6
5.9	6.1	6.2	6.3	6.5	6.6	6.8	6.9	7.1	7.2	0.8	4.4		8
6.1	6.2	0.4	6.5	6.7	6.8	7.0	7.1	7.2	7.4	11.1	4.8		8.0
6.2	6.3	6.5	6.6	6.8	7.0	7.1	7.3	7.4	7.6	1.4	5.2		2
6.4	6.5	6.7	6.8	7.0	7.2	7.3	7.5	7.6	7.8	1.7	5.6		4
6.5	6.7	6.8	7.0	7.2	7.3	7.5	7.7	7.8	8.0	2.0	6.0		6
6.7	6.9	7.0	7.2	7.3	7.5	7.7	7.8	8.0	8.2	2.2	6.3		8
6.8	7.0	7.2	7.3	7.5	7.7	7.8	8.0	8.2	8.3	12.5	6.6		9.0
7.0	7.2	7.3	7.5	7.7	7.8	8.0	8.2	8.3	8.5	2.8	7.0		2
7.1	7.3	7.5	7.7	7.8	8.0	8.2	8.4	8.5	8.7	3.1	7.4		4
7.3	7.5	7.6	7.8	8.0	8.2	8.3	8.5	8.7	8.9	3.3	7.8		6
7.4	7.6	7.8	8.0	8.2	8.4	8.5	8.7	8.9	9.1	3.6	8.2		8
7.6	7.8	8.0	8.1	8.3	8.5	8.7	8.9	9.1	9.3	13.9	8.5		10.0
8.0	8.2	8.4	8.6	8.8	8.9	9.1	9.3	9.5	9.7	4.6	9.5		5
8.3	8.5	8.7	8.9	9.2	9.4	9.6	9.8	10.0	10.2	5.3	20.3		11.0
8.7	8.9	9.1	9.4	9.6	9.8	10.0	10.2	0.4	0.7	6.0	1.3		5
9.1	9.3	9.5	9.8	10.0	10.2	0.4	0.7	0.9	1.1	6.7	2.2		12.0
9.5	9.7	10.0	10.2	10.4	10.6	10.8	11.1	11.4	11.6	17.4	23.2		5
9.9	10.1	0.4	0.6	0.8	1.1	1.3	1.6	1.8	2.1	8.0	4.1		13.0
10.3	0.5	0.8	1.0	1.3	1.5	1.8	2.0	2.3	2.5	8.8	5.0		5
0.6	0.9	1.2	1.4	1.7	1.9	2.2	2.4	2.7	3.0	9.4	6.0		14.0

TABLE 41—*Continued*

DISTANCE HORIZONTAL SUM OF AREAS VERTICAL QUANTITIES IN CUBIC YARDS

2	3	4	5	6	7	8	9	10	11	12	13	14	D'uble Areas
0.5	0.8	1.1	1.3	1.6	1.9	2.1	2.4	2.7	3.0	3.2	3.5	3.8	14.5
0.6	0.8	1.1	1.4	1.7	2.0	2.2	2.5	2.8	3.1	3.3	3.6	3.9	15.0
0.6	0.9	1.2	1.5	1.7	2.0	2.3	2.6	2.9	3.2	3.4	3.7	4.0	5
0.6	0.9	1.2	1.5	1.8	2.1	2.4	2.7	3.0	3.3	3.6	3.8	4.1	16.0
0.6	0.9	1.2	1.5	1.8	2.1	2.4	2.7	3.1	3.4	3.7	4.0	4.3	5
0.6	0.9	1.3	1.6	1.9	2.2	2.5	2.8	3.1	3.5	3.8	4.1	4.4	17.0
0.6	1.0	1.3	1.6	2.0	2.3	2.6	2.9	3.2	3.6	3.9	4.2	4.5	5
0.7	1.0	1.3	1.7	2.0	2.3	2.7	3.0	3.3	3.7	4.0	4.3	4.7	18.0
0.7	1.0	1.4	1.7	2.1	2.4	2.7	3.1	3.4	3.8	4.1	4.4	4.8	5
0.7	1.1	1.4	1.8	2.1	2.5	2.8	3.2	3.5	3.9	4.2	4.6	4.9	19.0
0.7	1.1	1.4	1.8	2.2	2.5	2.9	3.2	3.6	4.0	4.3	4.7	5.0	5
0.7	1.1	1.5	1.9	2.2	2.6	3.0	3.3	3.7	4.1	4.4	4.8	5.2	20.0
0.8	1.2	1.6	2.0	2.3	2.7	3.1	3.5	3.9	4.3	4.7	5.1	5.4	1
0.8	1.2	1.6	2.0	2.4	2.8	3.3	3.7	4.1	4.5	4.9	5.3	5.7	2
0.9	1.3	1.7	2.1	2.6	3.0	3.4	3.8	4.3	4.7	5.1	5.5	6.0	3
0.9	1.3	1.8	2.2	2.7	3.1	3.6	4.0	4.4	4.9	5.3	5.8	6.2	4
0.9	1.4	1.9	2.3	2.8	3.2	3.7	4.2	4.6	5.1	5.6	6.0	6.5	25.0
1.0	1.4	1.9	2.4	2.9	3.4	3.9	4.3	4.8	5.3	5.8	6.3	6.7	6
1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	5.5	6.0	6.5	7.0	7
1.0	1.6	2.1	2.6	3.1	3.6	4.2	4.7	5.2	5.7	6.2	6.7	7.3	8
1.1	1.6	2.1	2.7	3.2	3.8	4.3	4.8	5.4	5.9	6.4	7.0	7.5	9
1.1	1.7	2.2	2.8	3.3	3.9	4.4	5.0	5.5	6.1	6.7	7.2	7.8	30.0
1.2	1.7	2.3	2.9	3.4	4.0	4.6	5.2	5.7	6.3	6.9	7.5	8.0	1
1.2	1.8	2.4	3.0	3.6	4.2	4.7	5.3	6.0	6.5	7.1	7.7	8.3	2
1.2	1.8	2.4	3.0	3.7	4.3	4.9	5.5	6.1	6.7	7.3	8.0	8.6	3
1.3	1.9	2.5	3.1	3.8	4.4	5.0	5.7	6.3	6.9	7.5	8.2	8.8	4
1.3	1.9	2.6	3.2	3.9	4.5	5.2	5.8	6.5	7.1	7.8	8.4	9.1	35.0
1.3	2.0	2.7	3.3	4.0	4.7	5.3	6.0	6.7	7.3	8.0	8.7	9.3	6
1.4	2.1	2.7	3.4	4.1	4.8	5.5	6.2	6.9	7.5	8.2	8.9	9.6	7
1.4	2.1	2.8	3.5	4.2	4.9	5.6	6.3	7.0	7.7	8.4	9.2	9.8	8
1.4	2.2	2.9	3.6	4.3	5.0	5.8	6.5	7.2	7.9	8.7	9.4	10.1	9
1.5	2.2	3.0	3.7	4.4	5.2	5.9	6.7	7.4	8.1	8.9	9.7	0.4	40.0
1.5	2.3	3.0	3.8	4.5	5.3	6.1	6.8	7.6	8.3	9.1	9.9	0.6	1
1.6	2.3	3.1	3.9	4.7	5.4	6.2	7.0	7.8	8.5	9.3	10.1	0.9	2
1.6	2.4	3.2	4.0	4.8	5.6	6.4	7.2	8.0	8.8	9.6	10.4	1.2	3
1.6	2.4	3.3	4.1	4.9	5.7	6.5	7.3	8.2	9.0	9.8	10.6	11.4	4
1.7	2.5	3.3	4.2	5.0	5.8	6.7	7.5	8.3	9.2	10.0	0.9	1.7	45.0
1.7	2.6	3.4	4.3	5.1	6.0	6.8	7.7	8.5	9.4	0.2	1.1	1.9	6
1.7	2.6	3.5	4.3	5.2	6.1	7.0	7.8	8.7	9.6	0.5	1.3	2.2	7
1.8	2.7	3.6	4.4	5.3	6.2	7.1	8.0	8.9	9.8	0.7	1.6	2.4	8
1.8	2.7	3.6	4.5	5.4	6.4	7.3	8.2	9.1	10.0	10.9	11.8	12.7	9
1.8	2.8	3.7	4.6	5.6	6.5	7.4	8.3	9.3	0.2	1.1	2.1	2.9	50.0
1.9	2.9	3.9	4.8	5.8	6.7	7.7	8.7	9.6	0.6	1.6	2.5	3.5	2
2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	10.0	1.0	2.0	3.0	4.0	4
2.1	3.1	4.1	5.2	6.2	7.3	8.3	9.3	0.4	1.4	2.5	3.5	4.5	6
2.2	3.2	4.3	5.4	6.4	7.5	8.6	9.7	10.7	11.8	12.9	13.9	15.0	8
2.2	3.3	4.4	5.5	6.7	7.8	8.9	10.0	1.1	2.2	3.3	4.4	5.5	60.0
2.3	3.4	4.6	5.7	6.9	8.0	9.2	0.3	1.5	2.6	3.8	4.9	6.1	2
2.4	3.6	4.7	5.9	7.1	8.3	9.5	0.7	1.9	3.0	4.2	5.4	6.6	4
2.4	3.7	4.9	6.1	7.3	8.6	9.8	1.0	2.2	3.4	4.7	5.9	7.1	6
2.5	3.8	5.0	6.3	7.5	8.8	10.1	11.4	12.6	13.8	15.1	16.4	17.6	8
2.6	3.9	5.2	6.5	7.8	9.1	10.4	1.7	3.0	4.3	5.5	6.8	8.2	70.0
2.7	4.0	5.3	6.7	8.0	9.3	10.7	2.0	3.4	4.7	6.0	7.3	8.6	2
2.7	4.1	5.5	6.9	8.2	9.6	10.9	2.3	3.7	5.1	6.5	7.8	9.2	4

Table 41—*Continued*

Distance Horizontal Sum of Areas Vertical Quantities in Cubic Yards

15	16	17	18	19	20	21	22	23	24	25	26	27	D'uble Areas
4.0	4.3	4.6	4.8	5.1	5.4	5.6	5.9	6.2	6.5	6.7	6.9	7.3	14.5
4.2	4.4	4.7	5.0	5.3	5.6	5.8	6.1	6.4	6.7	6.9	7.2	7.5	15.0
4.3	4.6	4.9	5.2	5.5	5.7	6.0	6.3	6.6	6.9	7.2	7.5	7.8	5
4.5	4.7	5.0	5.3	5.6	5.9	6.2	6.5	6.8	7.1	7.4	7.7	8.0	16.0
4.6	4.9	5.2	5.5	5.8	6.1	6.4	6.7	7.0	7.3	7.7	8.0	8.3	5
4.7	5.1	5.3	5.7	6.0	6.3	6.6	6.9	7.2	7.6	7.9	8.2	8.5	17.0
4.9	5.2	5.5	5.8	6.2	6.5	6.8	7.1	7.5	7.8	8.1	8.4	8.8	5
5.0	5.3	5.7	6.0	6.3	6.7	7.0	7.4	7.7	8.0	8.4	8.7	9.0	18.0
5.1	5.5	5.8	6.2	6.5	6.8	7.2	7.5	7.9	8.2	8.6	8.9	9.3	5
5.3	5.6	6.0	6.3	6.7	7.0	7.4	7.7	8.1	8.5	8.8	9.2	9.5	19.0
5.4	5.8	6.1	6.5	6.8	7.2	7.6	7.9	8.3	8.7	9.0	9.4	9.8	5
5.6	5.9	6.3	6.7	7.0	7.4	7.8	8.2	8.5	8.9	9.3	9.7	10.0	20.0
5.8	6.2	6.6	7.0	7.4	7.8	8.2	8.6	9.0	9.3	9.7	10.1	0.5	1
6.1	6.5	6.9	7.3	7.7	8.1	8.6	9.0	9.4	9.8	10.2	0.6	1.0	2
6.4	6.8	7.2	7.7	8.1	8.5	8.9	9.4	9.8	10.2	0.6	1.1	1.5	3
6.7	7.1	7.5	8.0	8.4	8.9	9.3	9.8	10.2	10.7	11.1	11.6	12.0	4
7.0	7.4	7.9	8.3	8.8	9.3	9.7	10.2	0.7	1.1	1.6	2.1	2.5	25.0
7.2	7.7	8.2	8.7	9.1	9.6	10.1	0.6	1.1	1.6	2.0	2.5	3.0	6
7.5	8.0	8.5	9.0	9.5	10.0	0.5	1.0	1.5	2.0	2.5	3.0	3.5	7
7.8	8.3	8.8	9.3	9.8	0.4	0.9	1.4	1.9	2.4	3.0	3.5	4.0	8
8.1	8.6	9.1	9.7	10.2	10.7	11.3	11.8	12.4	12.9	13.4	13.9	14.5	9
8.3	8.9	9.5	10.0	0.5	1.1	1.7	2.2	2.8	3.3	3.9	4.5	5.0	30.0
8.6	9.2	9.8	0.3	0.9	1.5	2.1	2.6	3.2	3.8	4.3	4.9	5.5	1
8.9	9.5	10.1	0.7	1.3	1.9	2.5	3.0	3.6	4.2	4.8	5.4	6.0	2
9.2	9.8	0.4	1.0	1.6	2.2	2.9	3.5	4.1	4.7	5.3	5.9	6.5	3
9.5	10.1	10.7	11.3	12.0	12.6	13.3	13.9	14.5	15.1	15.7	16.4	17.0	4
9.7	0.3	1.0	1.7	2.3	2.9	3.6	4.3	4.9	5.5	6.2	6.9	7.5	35.0
10.0	0.7	1.3	2.0	2.7	3.3	4.0	4.7	5.3	6.0	6.7	7.3	8.0	6
0.3	0.9	1.7	2.3	3.0	3.7	4.4	5.1	5.8	6.5	7.1	7.8	8.5	7
0.6	1.3	2.0	2.7	3.4	4.1	4.8	5.5	6.2	6.9	7.6	8.3	9.0	8
10.8	11.6	12.3	13.0	13.7	14.5	15.2	15.9	16.6	17.3	18.1	18.8	19.5	9
1.2	1.8	2.6	3.3	4.1	4.8	5.6	6.3	7.1	7.8	8.5	9.3	20.0	40.0
1.4	2.1	2.9	3.7	4.4	5.2	6.0	6.7	7.5	8.1	9.0	9.7	0.5	1
1.7	2.4	3.2	4.0	4.8	5.5	6.3	7.1	7.9	8.7	9.4	20.2	1.0	2
2.0	2.7	3.5	4.3	5.1	5.9	6.7	7.5	8.3	9.1	9.9	0.7	1.5	3
12.2	13.1	13.9	14.7	15.5	16.3	17.1	17.9	18.7	19.6	20.4	21.2	22.0	4
2.5	3.3	4.2	5.0	5.9	6.7	7.5	8.3	9.2	20.0	0.8	1.7	2.5	45.0
2.9	3.6	4.5	5.3	6.2	7.1	7.9	8.7	9.6	0.4	1.3	2.2	3.0	6
3.1	3.9	4.9	5.7	6.5	7.4	8.3	9.1	20.1	0.9	1.7	2.6	3.5	7
3.4	4.2	5.1	6.0	6.9	7.8	8.7	9.6	0.4	1.3	2.2	3.2	4.0	8
13.6	14.5	15.4	16.3	17.2	18.1	19.1	20.0	20.8	21.8	22.7	23.6	24.5	9
3.9	4.8	5.7	6.7	7.6	8.5	9.5	0.4	1.3	2.3	3.2	4.1	5.0	50.0
4.4	5.4	6.4	7.4	8.3	9.3	20.2	1.2	2.2	3.2	4.1	5.1	6.0	2
5.0	6.0	7.0	8.0	9.0	20.0	1.0	2.0	3.0	4.0	5.0	6.0	7.0	4
5.6	6.6	7.6	8.7	9.7	0.8	1.8	2.8	3.8	4.8	5.9	6.9	8.0	6
16.1	17.2	18.3	19.4	20.4	21.5	22.5	23.6	24.7	25.7	26.8	27.8	29.0	8
6.7	7.8	8.9	20.0	1.1	2.2	3.4	4.4	5.6	6.6	7.7	8.8	30.0	60.0
7.2	8.4	9.5	0.7	1.8	2.9	4.2	5.2	6.4	7.6	8.7	9.8	1.0	2
7.8	8.9	20.2	1.4	2.5	3.7	4.9	6.0	7.3	8.4	9.6	30.8	2.0	4
8.4	9.5	0.8	2.0	3.2	4.4	5.7	6.8	8.1	9.3	30.6	1.7	3.0	6
18.9	20.1	21.4	22.6	23.9	25.2	26.4	27.7	29.0	30.2	31.5	32.7	34.0	8
9.4	0.7	2.0	3.4	4.6	5.9	7.2	8.5	9.8	1.1	2.4	3.7	5.0	70.0
20.0	1.4	2.6	4.0	5.4	6.7	8.0	9.4	30.7	2.0	3.4	4.6	6.0	2
06	1.8	3.3	4.7	6.0	7.4	8.8	30.2	1.5	2.9	4.3	5.7	7.0	4

TABLE 41—*Continued*

DISTANCE HORIZONTAL SUM OF AREAS VERTICAL QUANTITIES IN CUBIC YARDS

28	29	30	31	32	33	34	35	36	37	38	39	40	D'uble Areas
7.5	7.8	8.1	8.3	8.6	8.8	9.1	9.4	9.7	9.9	10.2	10.5	10.7	14.5
7.8	8.0	8.3	8.6	8.9	9.2	9.5	9.7	10.0	10.3	0.6	0.9	1.1	15.0
8.0	8.3	8.6	8.9	9.2	9.5	9.8	10.0	0.3	0.6	0.9	1.2	1.5	5
8.3	8.6	8.9	9.2	9.5	9.8	10.1	0.3	0.7	1.0	1.3	1.6	1.9	16.0
8.5	8.9	9.2	9.5	9.8	10.1	0.4	0.7	1.0	1.3	1.6	1.9	2.2	5
8.8	9.1	9.4	9.8	10.1	10.4	10.7	11.0	11.3	11.7	11.9	12.3	12.6	17.0
9.1	9.4	9.7	10.1	0.4	0.7	1.0	1.3	1.7	2.0	2.3	2.6	3.0	5
9.3	9.7	10.0	0.3	0.7	1.0	1.3	1.7	2.0	2.3	2.7	3.0	3.3	18.0
9.6	9.9	0.3	0.6	1.0	1.3	1.7	2.0	2.3	2.7	3.0	3.3	3.7	5
9.8	10.2	0.5	0.9	1.3	1.6	1.9	2.3	2.7	3.0	3.3	3.7	4.1	19.0
10.1	10.5	10.8	11.2	11.6	11.9	12.3	12.6	13.0	13.3	13.7	14.1	14.4	5
0.4	0.7	1.1	1.5	1.9	2.2	2.6	2.9	3.3	3.7	4.1	4.5	4.8	20.0
0.9	1.3	1.7	2.1	2.5	2.8	3.2	3.6	4.0	4.4	4.8	5.2	5.5	1
1.4	1.8	2.2	2.6	3.1	3.4	3.9	4.2	4.7	5.1	5.5	5.9	6.3	2
1.9	2.4	2.8	3.2	3.6	4.1	4.5	4.9	5.3	5.7	6.2	6.6	7.1	3
12.5	12.9	13.3	13.8	14.2	14.7	15.1	15.5	16.0	16.4	16.9	17.3	17.8	4
2.9	3.4	3.9	4.4	4.8	5.3	5.7	6.2	6.7	7.1	7.6	8.1	8.5	25.0
3.5	3.9	4.4	4.9	5.4	5.9	6.4	6.8	7.3	7.9	8.3	8.8	9.3	6
4.0	4.5	5.0	5.5	6.0	6.5	7.0	7.5	8.0	8.5	9.0	9.5	20.0	7
4.5	5.1	5.5	6.1	6.6	7.1	7.6	8.1	8.7	9.2	9.7	20.2	0.7	8
15.1	15.5	16.1	16.6	17.2	17.7	18.3	18.8	19.3	19.9	20.4	20.9	21.5	9
5.5	6.1	6.7	7.2	7.8	8.3	8.9	9.4	9.9	20.6	1.2	1.7	2.2	30.0
6.1	6.6	7.2	7.8	8.4	8.9	9.5	20.1	20.7	1.2	1.8	2.4	2.9	1
6.6	7.2	7.7	8.3	8.9	9.6	20.2	0.6	1.3	1.9	2.5	3.2	3.7	2
7.1	7.7	8.3	8.9	9.5	20.2	0.7	1.4	1.9	2.6	3.2	3.8	4.4	3
17.6	18.3	18.9	19.5	20.2	20.8	21.4	22.0	22.7	23.3	23.8	24.6	25.2	4
8.1	8.7	9.5	20.1	0.7	1.3	2.1	2.7	3.3	3.9	4.7	5.3	5.9	35.0
8.7	9.3	20.0	0.7	1.3	1.9	2.7	3.3	3.9	4.6	5.3	6.0	6.7	6
9.2	9.9	0.6	1.2	1.9	2.6	3.2	3.9	4.6	5.3	6.0	6.7	7.4	7
9.7	20.4	1.1	1.8	2.5	3.2	3.9	4.6	5.3	6.0	6.7	7.4	8.1	8
20.2	20.9	21.7	22.3	23.2	23.8	24.6	25.3	25.9	26.7	27.4	28.2	28.9	9
0.7	1.4	2.2	2.9	3.7	4.4	5.2	5.9	6.6	7.4	8.1	8.8	9.6	40.0
1.3	1.9	2.8	3.6	4.3	5.1	5.7	6.5	7.3	8.1	8.8	9.6	30.4	1
1.8	2.6	3.3	4.2	4.8	5.6	6.4	7.2	7.9	8.7	9.6	30.3	1.0	2
2.3	3.1	3.8	4.7	5.4	6.2	7.1	7.8	8.6	9.4	30.2	1.1	1.8	3
22.8	23.6	24.4	25.2	26.1	26.8	27.7	28.4	29.3	30.2	30.9	31.7	32.6	4
3.3	4.2	5.0	5.8	6.6	7.5	8.4	9.2	9.9	0.8	1.7	2.5	3.4	45.0
3.8	4.7	5.6	6.4	7.2	8.1	8.9	9.8	30.6	1.5	2.4	3.2	4.1	6
4.3	5.2	6.1	6.9	7.8	8.7	9.6	30.4	1.3	2.2	3.0	3.9	4.8	7
4.8	5.7	6.7	7.6	8.4	9.3	30.2	1.1	2.0	2.8	3.7	4.7	5.5	8
25.4	26.3	27.2	28.2	29.0	29.9	30.8	31.7	32.6	33.6	34.5	35.4	36.3	9
5.9	6.8	7.8	8.7	9.6	30.5	1.4	2.4	3.4	4.2	5.2	6.2	7.1	50.0
6.9	7.8	8.8	9.8	30.8	1.7	2.7	3.7	4.6	5.6	6.6	7.5	8.5	2
7.9	8.9	9.9	30.9	2.0	3.0	4.0	5.0	5.9	6.9	8.0	9.0	40.0	4
9.0	30.1	31.1	2.1	3.2	4.2	5.2	6.2	7.3	8.3	9.4	40.4	1.5	6
30.1	31.1	32.2	33.2	34.4	35.4	36.5	37.5	38.6	39.6	40.8	41.8	42.9	8
1.1	2.2	3.3	4.4	5.6	6.6	7.7	8.9	40.0	41.1	2.2	3.4	4.4	60.0
2.1	3.2	4.4	5.6	6.7	7.8	9.0	40.1	1.3	2.4	3.6	4.8	5.9	2
3.2	4.4	5.5	6.6	7.8	9.1	40.2	1.4	2.6	3.8	5.0	6.2	7.4	4
4.2	5.4	6.6	7.8	9.1	40.2	1.5	2.7	3.9	5.2	6.4	7.6	8.8	6
35.2	36.4	37.7	39.0	40.2	41.5	42.8	44.0	45.2	46.5	47.8	49.0	50.4	8
6.3	7.6	8.8	40.1	1.4	2.8	4.0	5.4	6.6	8.0	9.2	50.5	1.8	70.0
7.3	8.7	9.9	1.3	2.6	4.0	5.3	6.6	8.0	9.2	50.6	2.0	3.3	2
8.4	9.7	41.1	2.5	3.8	5.2	6.6	7.9	9.4	50.7	2.1	3.4	4.8	4

TABLE 41—*Continued*

DISTANCE HORIZONTAL SUM OF AREAS VERTICAL QUANTITIES IN CUBIC YARDS

41	42	43	44	45	46	47	48	49	50	75	100		D'uble Areas
11.0	11.3	11.5	11.8	12.1	12.3	12.6	12.9	13.1	13.4	20.2	26.8	—	14.5
1.4	1.7	1.9	2.2	2.5	2.8	3.0	3.3	3.6	3.9	0.8	7.8	—	15.0
1.8	2.1	2.3	2.6	2.9	3.2	3.5	3.8	4.1	4.4	1.5	8.7	—	5
2.1	2.4	2.7	3.0	3.3	3.6	3.9	4.2	4.5	4.8	2.2	9.6	—	16.0
2.5	2.8	3.1	3.4	3.7	4.1	4.3	4.7	4.9	5.3	2.8	30.5	—	5
12.9	13.2	13.5	13.8	14.2	14.5	14.8	15.1	15.4	15.7	23.6	31.4	—	17.0
3.3	3.6	3.9	4.3	4.6	4.9	5.2	5.5	5.9	6.2	4.3	2.4	—	5
3.7	4.0	4.3	4.7	5.0	5.3	5.7	6.0	6.3	6.7	4.9	3.3	—	18.0
4.1	4.4	4.7	5.1	5.4	5.7	6.1	6.4	6.7	7.1	5.7	4.2	—	5
4.4	4.7	5.1	5.5	5.8	6.1	6.5	6.9	7.2	7.6	6.4	5.2	—	19.0
14.8	15.1	15.5	15.9	16.3	16.6	16.9	17.3	17.7	18.1	27.1	36.1	—	5
5.2	5.5	5.9	6.3	6.7	7.1	7.4	7.7	8.1	8.5	7.8	7.0	—	20.0
5.9	6.3	6.7	7.1	7.5	7.9	8.3	8.7	9.0	9.5	9.2	8.8	—	1
6.7	7.1	7.5	7.9	8.3	8.7	9.1	9.5	9.9	20.4	30.6	40.7	—	2
7.5	7.9	8.3	8.7	9.1	9.6	20.0	20.4	20.8	1.3	1.9	2.6	—	3
18.2	18.6	19.1	19.5	20.0	20.4	20.8	21.3	21.8	22.2	33.2	44.4	—	4
9.0	9.5	9.9	20.3	0.8	1.3	1.7	2.2	2.7	3.2	4.7	6.2	—	25.0
9.7	20.2	20.7	1.2	1.7	2.2	2.6	3.1	3.6	4.1	6.1	8.2	—	6
20.5	1.0	1.5	2.0	2.5	3.0	3.5	4.0	4.5	5.0	7.5	50.0	—	7
1.3	1.8	2.3	2.8	3.3	3.8	4.4	4.8	5.4	5.9	8.8	1.8	—	8
22.0	22.6	23.1	23.7	24.2	24.7	25.2	25.8	26.3	26.8	40.3	53.7	—	9
2.8	3.3	3.8	4.4	5.0	5.5	6.1	6.7	7.2	7.8	1.6	5.5	—	30.0
3.5	4.1	4.7	5.2	5.8	6.4	6.9	7.6	8.1	8.7	3.2	7.3	—	1
4.3	4.8	5.4	6.1	6.6	7.2	7.8	8.4	9.1	9.6	4.4	9.2	—	2
5.0	5.7	6.3	6.8	7.5	8.1	8.7	9.3	9.9	30.6	5.8	61.0	—	3
25.7	26.4	27.0	27.7	28.3	28.9	29.6	30.2	30.8	31.4	47.2	62.9	—	4
6.6	7.2	7.8	8.5	9.2	9.8	30.4	1.1	1.7	2.4	8.6	4.8	—	35.0
7.3	8.0	8.6	9.3	30.0	30.6	1.3	2.0	2.6	3.3	9.9	6.7	—	6
8.1	8.8	9.4	30.1	0.8	1.5	2.2	2.8	3.6	4.3	51.4	8.5	—	7
8.8	9.6	30.2	1.0	1.6	2.4	3.1	3.7	4.5	5.2	2.8	70.4	—	8
29.6	30.4	31.0	31.7	32.5	33.2	33.8	34.6	35.4	36.1	54.1	72.1	—	9
30.4	1.2	1.8	2.6	3.3	4.0	4.8	5.6	6.3	7.0	5.5	4.0	—	40.0
1.2	1.8	2.6	3.4	4.2	4.8	5.6	6.4	7.2	8.0	6.9	5.8	—	1
1.8	2.7	3.4	4.2	5.0	5.8	6.6	7.3	8.2	8.9	8.3	7.8	—	2
2.6	3.4	4.2	5.0	5.8	6.6	7.4	8.2	9.0	9.8	9.6	9.6	—	3
33.4	34.2	35.0	35.8	36.7	37.4	38.3	39.2	39.9	40.8	61.1	81.5	—	4
4.2	4.9	5.8	6.7	7.4	8.3	9.2	9.9	40.7	1.6	2.4	3.4	—	45.0
4.8	5.7	6.6	7.4	8.3	9.1	40.0	40.9	1.7	2.6	3.8	5.1	—	6
5.7	6.6	7.4	8.3	9.2	40.0	0.9	1.8	2.7	3.5	5.3	7.0	—	7
6.4	7.3	8.2	9.2	40.0	0.8	1.7	2.6	3.5	4.4	6.7	8.9	—	8
37.2	38.1	39.0	39.9	40.8	41.7	42.6	43.5	44.4	45.3	68.1	90.6	—	9
7.9	8.8	9.8	40.7	1.6	2.6	3.5	4.4	5.3	6.4	9.3	2.6	—	50.0
9.5	40.4	41.3	2.3	3.3	4.2	5.2	6.2	7.2	8.2	72.2	6.3	—	2
41.0	2.0	3.0	4.0	5.0	6.0	7.0	8.0	9.0	50.0	5.0	100.0	—	4
2.5	3.5	4.6	5.6	6.6	7.7	8.7	9.8	50.8	1.8	7.8	03.6	—	6
44.1	45.2	46.2	47.3	48.4	49.4	50.5	51.5	52.6	53.7	80.5	107.3	—	8
5.6	6.7	7.8	8.9	50.0	51.1	2.2	3.3	4.4	5.5	3.4	11.0	—	60.0
7.1	8.2	9.4	50.5	1.6	2.8	4.0	5.1	6.2	7.4	6.1	14.8	—	2
8.6	9.7	50.9	2.1	3.3	4.5	5.7	6.9	8.1	9.3	8.9	18.6	—	4
50.2	51.3	2.5	3.7	5.0	6.1	7.4	8.6	9.9	61.1	91.7	22.1	—	6
51.6	52.8	54.1	55.4	56.7	58.0	59.2	60.4	61.7	63.0	94.5	125.9	—	8
3.1	4.4	5.7	7.0	8.3	9.6	60.9	2.2	3.5	4.8	7.2	29.5	—	70.0
4.7	6.0	7.3	8.6	60.0	61.3	2.6	4.0	5.4	6.6	100.0	33.2	—	2
6.2	7.6	8.9	60.3	1.7	3.1	4.4	5.8	7.2	8.6	02.0	37.1	—	4

TABLE 41—*Continued*

DISTANCE HORIZONTAL SUM OF AREAS VERTICAL QUANTITIES IN CUBIC YARDS

2	3	4	5	6	7	8	9	10	11	12	13	14	D'uble Areas
2.8	4.2	5.6	7.0	8.5	9.9	11.3	12.7	14.1	15.5	16.9	18.3	19.7	76.0
2.9	4.3	5.8	7.2	8.7	10.1	1.6	3.0	4.5	5.9	7.4	8.8	20.2	8
3.0	4.4	5.9	7.4	8.9	0.4	1.9	3.3	4.9	6.3	7.8	9.3	0.8	80.0
3.0	4.6	6.1	7.6	9.1	0.7	2.2	3.7	5.2	6.7	8.2	9.8	1.3	2
3.1	4.7	6.2	7.8	9.3	0.9	2.5	4.0	5.6	7.1	8.7	20.2	1.7	4
3.2	4.8	6.4	8.0	9.6	11.2	12.7	14.3	15.9	17.5	19.1	20.7	22.3	6
3.3	4.9	6.5	8.1	9.8	1.4	3.1	4.7	6.3	7.9	9.5	1.2	2.8	8
3.3	5.0	6.7	8.3	10.0	1.7	3.3	5.0	6.7	8.3	20.0	1.7	3.4	90.0
3.4	5.1	6.8	8.5	0.2	1.9	3.6	5.4	7.1	8.7	0.4	2.1	3.8	2
3.5	5.2	7.0	8.7	0.5	2.2	3.9	5.7	7.4	9.2	0.8	2.6	4.4	4
3.5	5.3	7.1	8.9	10.7	12.5	14.2	16.0	17.8	19.5	21.3	23.1	24.9	6
3.6	5.4	7.3	9.1	0.9	2.7	4.5	6.4	8.2	9.9	1.8	3.6	5.4	8
3.7	5.6	7.4	9.3	1.1	3.0	4.8	6.7	8.5	20.4	2.2	4.1	6.0	100.0
3.9	5.8	7.8	9.7	1.7	3.6	5.5	7.5	9.5	1.4	3.3	5.3	7.2	05
4.1	6.1	8.1	10.2	2.2	4.3	6.3	8.4	20.4	2.4	4.4	6.5	8.6	10
4.3	6.4	8.5	10.7	12.8	14.9	17.0	19.1	21.3	23.4	25.5	27.7	29.8	15
4.4	6.7	8.9	1.1	3.3	5.5	7.8	20.0	2.3	4.4	6.6	8.8	31.2	20
4.6	6.9	9.2	1.6	3.9	6.2	8.5	0.8	3.2	5.4	7.7	30.2	2.4	125.0
4.8	7.2	9.6	2.1	4.5	6.9	9.3	1.7	4.1	6.5	8.8	1.4	3.7	30
5.0	7.5	10.0	2.5	5.0	7.5	20.0	2.5	5.0	7.5	9.9	2.5	5.0	35
5.2	7.8	10.4	12.9	15.5	18.2	20.8	23.4	25.9	28.5	31.1	33.7	36.4	40
5.4	8.0	0.7	3.4	6.1	8.8	1.5	4.2	6.8	9.5	2.2	4.8	7.6	45
5.6	8.3	1.1	3.9	6.7	9.5	2.3	5.0	7.8	30.6	3.4	6.2	8.8	150.0
5.7	8.6	1.5	4.3	7.2	20.1	2.9	5.8	8.7	1.6	4.5	7.3	40.2	55
5.9	8.9	1.9	4.8	7.8	0.7	3.7	6.7	9.6	2.6	5.6	8.5	1.5	60
6.1	9.2	12.3	15.3	18.3	21.4	24.4	27.5	30.6	33.6	36.6	39.7	42.8	65
6.3	9.5	2.6	5.8	8.9	2.1	5.2	8.3	1.5	4.6	7.7	40.9	4.1	70
6.5	9.7	3.0	6.2	9.4	2.7	5.9	9.2	2.4	5.6	8.9	2.1	5.5	175.0
6.7	10.0	3.3	6.7	20.0	3.3	6.7	30.0	3.3	6.7	40.0	3.3	6.6	80
6.9	0.3	3.7	7.1	0.6	4.0	7.4	0.9	4.2	7.7	1.2	4.5	8.0	85
7.0	10.5	14.1	17.6	21.2	24.6	28.2	31.7	35.2	38.7	42.2	45.7	49.3	90
7.2	0.8	4.5	8.1	1.6	5.2	8.8	2.5	6.2	9.7	3.3	7.0	50.5	95
7.4	1.1	4.9	8.5	2.2	5.9	9.6	3.4	7.1	40.8	4.4	8.2	1.9	200.0
7.8	1.7	5.6	9.5	3.4	7.2	31.1	5.0	8.9	2.8	6.7	50.5	4.4	10
8.1	2.2	6.3	20.4	4.4	8.5	2.6	6.7	40.8	4.8	8.8	3.0	7.1	20
8.5	12.7	17.1	21.3	25.6	29.8	34.1	38.4	42.6	46.8	51.1	55.4	59.6	30
8.9	3.3	7.7	2.2	6.6	31.1	5.6	40.0	4.4	8.8	3.3	7.8	62.1	40
9.2	3.9	8.5	3.1	7.8	2.4	7.0	1.7	6.4	50.9	5.6	60.2	4.8	250.0
9.6	4.5	9.3	4.1	8.9	3.7	8.5	3.4	8.2	2.9	7.8	2.7	7.4	60
10.0	5.0	20.0	5.0	30.0	5.0	9.9	5.0	50.0	5.0	60.0	4.9	70.0	70
10.4	15.6	20.7	25.9	31.1	36.3	41.4	46.7	51.9	57.0	62.2	67.4	72.5	80
0.8	6.1	1.4	6.8	2.2	7.6	3.0	8.3	3.8	9.1	4.4	9.8	5.2	90
1.1	6.7	2.2	7.8	3.3	8.8	4.4	50.0	5.6	61.1	6.8	72.2	7.9	300.0
1.5	7.2	2.9	8.6	4.4	40.2	5.9	1.8	7.4	3.1	8.8	4.5	80.4	10
1.9	7.8	3.6	9.6	5.5	1.4	7.4	3.3	9.3	5.2	71.1	7.0	3.0	20
12.2	18.3	24.4	30.6	36.6	42.8	48.8	55.0	61.2	67.2	73.3	79.4	85.6	30
2.6	8.9	5.2	1.4	7.7	4.1	50.5	6.7	2.9	9.2	5.5	81.8	8.2	40
3.0	9.5	5.9	2.4	8.8	5.3	1.8	8.3	4.8	71.3	7.8	4.2	90.8	350.0
3.3	20.0	6.6	3.3	9.9	6.6	3.4	60.0	6.8	3.3	80.0	6.8	3.3	60
3.7	0.6	7.4	4.3	41.1	7.9	4.8	1.6	8.5	5.3	2.1	9.0	6.0	70
14.1	21.2	28.2	35.2	42.2	49.2	56.3	63.3	70.3	77.4	84.3	91.5	98.5	80
4.4	1.6	8.8	6.1	3.3	50.6	7.8	5.0	2.3	9.4	6.6	3.9	101.1	90
4.8	2.2	9.6	7.1	4.4	1.8	9.2	6.7	4.1	81.5	8.9	6.3	3.6	400.0

Table 41—*Continued*

Distance Horizontal Sum of Areas Vertical Quantities in Cubic Yards

15	16	17	18	19	20	21	22	23	24	25	26	27	D'uble Areas
21.2	22.5	23.9	25.3	26.7	28.2	29.6	31.0	32.4	33.8	35.2	36.6	38.0	76.0
1.7	3.1	4.6	6.0	7.4	8.9	30.3	1.8	3.2	4.7	6.0	7.5	9.0	8
2.2	3.7	5.2	6.7	8.2	9.6	1.1	2.6	4.1	5.6	7.0	8.5	40.0	80.0
2.8	4.3	5.8	7.3	8.9	30.4	1.8	3.4	4.9	6.4	7.9	9.4	1.0	2
3.3	4.8	6.4	8.0	9.6	1.2	2.7	4.2	5.8	7.3	8.8	40.4	2.0	4
23.8	25.5	27.1	28.6	30.2	31.8	33.4	35.0	36.6	38.2	39.8	41.4	43.0	6
4.4	6.1	7.7	9.3	0.9	2.6	4.2	5.8	7.5	9.1	40.7	2.3	4.0	8
5.0	6.7	8.3	30.0	1.7	3.4	5.0	6.6	8.4	40.0	1.6	3.3	5.0	90.0
5.6	7.2	8.9	0.6	2.3	4.1	5.8	7.5	9.2	0.9	2.6	4.3	6.0	2
6.1	7.8	9.6	1.3	3.1	4.8	6.5	8.2	40.0	1.8	3.5	5.2	7.0	4
26.7	28.4	30.2	32.0	33.7	35.5	37.3	39.0	40.8	42.7	44.4	46.2	48.0	6
7.2	9.0	0.8	2.6	4.4	6.3	8.0	9.8	1.7	3.6	5.4	7.1	9.0	8
7.8	9.6	1.5	3.3	5.2	7.0	8.9	40.8	2.6	4.4	6.3	8.1	50.0	100.0
9.2	31.2	3.0	5.0	7.0	8.9	40.8	2.7	4.7	6.6	8.5	50.5	2.5	05
30.6	2.6	4.6	6.6	8.7	40.7	2.7	4.7	6.8	8.8	50.9	2.9	5.0	10
32.0	34.1	36.2	38.4	40.5	42.6	44.7	46.8	48.9	51.0	53.2	55.4	57.5	15
3.3	5.5	7.7	9.9	2.2	4.4	6.6	8.8	51.0	3.3	5.5	7.8	60.0	20
4.6	7.0	9.3	41.6	3.9	6.3	8.6	50.9	3.2	5.5	7.8	60.1	2.5	125.0
6.1	8.5	40.9	3.3	5.7	8.2	50.5	2.9	5.3	7.8	60.2	2.6	5.0	30
7.5	40.0	2.5	5.0	7.5	50.0	2.5	5.0	7.5	60.0	2.5	5.0	7.5	35
38.8	41.4	44.0	46.6	49.2	51.8	54.4	57.0	59.6	62.2	64.8	67.4	70.0	40
40.2	2.9	5.6	8.3	51.0	3.7	6.3	9.9	61.7	4.4	7.0	9.8	2.5	45
1.6	4.4	7.2	9.9	2.8	5.7	8.2	61.1	3.9	6.6	9.3	72.2	5.0	150.0
3.0	5.9	8.7	51.6	4.5	7.6	60.3	3.1	6.0	8.8	71.8	4.6	7.5	55
4.4	7.3	50.4	3.3	6.2	9.3	2.1	5.1	8.1	71.1	4.0	7.0	80.0	60
45.8	48.8	52.	55.0	58.0	61.0	64.2	67.1	70.3	73.4	76.2	79.3	82.5	65
7.2	50.5	3.5	6.6	9.8	3.0	6.0	9.2	2.3	5.5	8.7	81.8	5.0	70
8.6	1.8	5.0	8.3	61.5	4.8	8.0	71.2	4.6	7.7	81.0	4.3	7.5	175.0
50.0	3.3	6.6	60.0	3.3	6.8	9.9	3.2	6.7	80.0	3.2	6.7	90.0	80
1.4	4.8	8.1	1.6	5.0	8.5	71.9	5.3	8.8	2.2	5.6	9.0	2.5	85
52.8	56.2	59.8	63.3	66.8	70.4	73.8	77.3	80.9	84.3	87.9	91.7	95.0	90
4.0	7.8	61.3	5.0	8.7	2.1	5.7	9.4	3.0	6.7	90.2	3.9	7.5	95
5.5	9.2	2.9	6.7	70.3	4.0	7.7	81.4	5.1	8.9	2.8	6.4	100.0	200.0
8.3	62.1	6.0	70.0	3.8	7.8	81.7	5.5	9.4	93.4	7.2	101.2	05.0	10
61.0	5.1	9.3	3.2	7.4	81.5	5.5	9.5	93.7	7.8	101.9	06.0	10.0	20
53.9	68.0	72.4	76.6	80.9	85.2	89.4	93.7	98.0	102.2	106.5	110.8	115.0	30
6.5	71.0	5.5	9.9	4.3	8.9	93.2	7.8	102.2	106.8	11.1	15.5	20.0	40
9.4	4.0	8.6	83.2	7.9	92.5	7.1	101.9	06.5	11.1	15.9	20.5	25.0	250.0
72.1	7.0	81.8	6.5	91.4	6.5	101.2	06.0	10.7	15.5	20.4	25.3	30.0	60
5.0	80.0	5.0	90.0	4.9	100.0	05.0	10.0	15.1	20.0	25.0	30.0	35.0	70
7.8	82.9	88.1	93.2	98.4	103.8	108.9	114.1	119.2	124.5	129.5	134.8	140.0	80
0.6	5.9	91.2	6.5	102.1	07.4	12.9	18.1	23.5	28.9	34.3	39.8	45.0	90
3.2	8.9	4.4	100.0	05.7	11.1	16.8	22.2	29.7	33.3	38.9	44.5	50.0	300.0
6.0	91.8	7.5	03.3	09.2	14.8	20.6	26.3	32.1	37.9	43.5	49.3	55.0	10
9.0	4.7	100.9	06.8	12.7	18.6	24.3	30.3	36.2	42.2	48.1	54.1	60.0	20
1.5	97.7	103.9	110.0	116.1	122.2	128.3	134.5	140.6	146.8	152.8	158.9	165.0	30
4.5	100.7	07.1	13.2	19.6	26.0	32.2	38.5	44.9	51.1	57.2	63.8	70.0	40
7.2	03.8	10.2	16.7	23.2	29.7	36.2	42.5	49.1	55.5	62.0	68.5	75.0	350.0
0.0	06.6	13.4	20.0	26.8	33.3	40.0	46.6	53.2	60.0	66.8	73.4	80.0	60
2.8	09.6	16.4	23.2	30.2	37.0	43.8	50.7	57.5	64.5	71.2	78.1	85.0	70
5.6	112.5	119.6	126.8	133.8	140.8	147.8	154.8	161.8	168.9	175.9	183.0	190.0	80
3.2	15.5	22.9	30.0	37.2	44.3	51.7	58.9	66.1	73.4	80.5	87.8	95.0	90
1.1	18.5	25.9	33.3	40.7	48.1	55.6	63.0	70.4	77.8	85.2	92.6	200.0	400.0

TABLE 41—*Continued*

DISTANCE HORIZONTAL SUM OF AREAS VERTICAL QUANTITIES IN CUBIC YARDS

28	29	30	31	32	33	34	35	36	37	38	39	40	D'uble Areas
39.4	40.8	42.3	43.6	45.1	46.5	47.9	49.3	50.7	52.1	53.5	54.9	56.3	76.0
40.4	1.8	3.3	4.8	6.2	7.7	9.1	50.5	2.0	3.5	4.9	6.4	7.8	8
1.5	3.0	4.4	5.9	7.4	8.8	50.3	1.8	3.3	4.8	6.3	7.8	9.2	80.0
2.5	4.1	5.6	7.1	8.6	50.1	1.7	3.2	4.7	6.2	7.7	9.2	60.8	2
3.6	5.2	6.7	8.2	9.8	1.3	2.9	4.5	6.0	7.5	9.1	60.7	2.3	4
44.6	46.2	47.8	49.3	51.0	52.5	54.2	55.7	57.3	58.9	60.5	62.1	63.7	6
5.6	7.2	8.8	50.5	2.1	3.7	5.4	7.0	8.7	60.3	1.9	3.5	5.2	8
6.7	8.3	50.0	1.7	3.3	5.0	6.7	8.3	60.0	1.6	3.3	5.0	6.6	90.0
7.7	9.4	1.1	2.8	4.5	6.2	7.9	9.6	1.3	3.0	4.7	6.4	8.2	2
8.8	50.5	2.2	4.0	5.7	7.5	9.2	61.0	2.7	4.4	6.2	7.9	9.7	4
49.8	51.5	53.3	55.1	56.9	58.7	60.4	62.2	64.0	65.8	67.6	69.4	71.1	6
50.8	2.6	4.4	6.3	8.1	9.9	1.7	3.5	5.3	7.2	8.9	70.8	2.6	8
1.8	3.7	5.5	7.4	9.3	61.1	3.0	4.8	6.6	8.5	70.3	2.2	4.0	100.0
4.4	6.4	8.3	60.3	62.2	4.2	6.1	8.1	70.0	72.0	3.9	5.8	7.8	05
7.0	9.1	61.1	3.2	5.2	7.2	9.3	71.3	3.4	5.4	7.4	9.5	81.5	10
59.7	61.8	64.0	66.0	68.1	70.4	72.5	74.5	76.7	78.8	81.0	83.1	85.2	15
62.3	4.5	6.7	8.9	71.1	3.4	5.5	7.8	80.0	82.2	4.5	6.7	9.0	20
4.8	7.2	9.5	71.8	4.1	6.5	8.8	81.0	3.4	5.6	8.0	90.3	92.7	125.0
7.3	9.8	72.1	4.5	7.0	9.4	81.8	4.2	6.6	9.0	91.4	3.9	6.1	30
70.0	72.5	5.0	7.5	80.0	82.5	5.0	7.5	90.0	92.5	5.0	7.5	100.0	35
72.6	75.2	77.8	80.5	83.0	85.6	88.1	90.7	93.4	96.0	98.5	101.1	103.7	40
.5.2	7.9	80.5	3.2	5.9	8.6	91.3	4.0	6.7	9.4	102.0	04.8	07.5	45
7.8	80.6	3.4	6.1	8.9	91.7	4.5	7.2	100.0	102.8	05.6	08.3	11.1	150.0
80.4	3.2	6.2	9.0	91.9	4.7	7.6	100.5	03.4	06.2	09.1	12.0	14.8	55
2.9	5.9	8.8	91.8	4.7	7.7	100.8	03.8	06.7	09.7	12.6	15.6	18.5	60
85.5	88.5	91.6	94.7	97.7	100.9	103.9	107.0	110.0	113.1	116.1	119.2	122.2	65
8.1	91.3	4.4	7.6	100.8	03.9	07.1	10.2	13.3	16.6	19.7	22.8	26.0	70
90.8	4.0	7.3	100.5	03.8	70.0	10.2	13.4	16.7	20.0	23.2	26.4	29.6	175.0
3.4	6.6	100.0	03.3	06.8	111.1	13.4	16.8	20.0	23.3	26.7	30.1	33.4	80
6.0	9.4	02.8	06.2	09.6	13.2	16.5	19.9	23.4	26.8	30.2	33.7	37.1	85
98.6	102.1	105.6	109.2	112.8	116.1	119.7	123.2	126.7	130.2	133.8	137.3	140.8	90
101.2	04.8	08.4	12.0	15.6	19.2	22.9	26.4	30.0	33.8	37.2	40.9	44.5	95
03.7	07.4	11.1	14.9	18.6	22.2	26.0	29.6	33.3	37.0	40.6	44.4	48.1	200.0
08.8	12.8	16.6	20.6	24.4	28.4	32.2	36.2	40.0	44.0	47.8	51.6	55.6	10
14.0	18.2	22.2	26.4	30.4	34.4	38.6	42.6	46.8	50.8	54.8	59.0	63.0	20
119.4	123.6	127.8	132.0	136.2	140.6	145.0	149.0	153.4	157.6	162.0	166.2	170.4	30
24.6	29.0	33.4	37.8	42.2	46.8	51.0	55.6	60.0	64.4	69.0	73.4	78.0	40
29.6	34.4	39.0	43.6	48.2	53.0	57.6	62.0	66.8	71.4	76.0	80.6	85.4	250.0
34.6	39.4	44.2	49.0	54.0	58.8	63.6	68.4	73.2	78.0	82.8	87.8	92.5	60
40.0	45.0	50.0	55.0	60.0	65.0	70.0	75.0	80.0	85.0	90.0	95.0	200.0	70
145.2	150.4	155.6	161.0	166.0	171.2	176.2	181.4	186.8	192.0	197.0	202.2	207.4	80
50.4	55.8	61.0	66.4	71.8	77.2	82.6	88.0	93.3	98.8	204.0	09.6	14.6	90
55.6	61.2	66.8	72.2	77.8	83.4	89.0	94.4	200.0	205.6	11.2	16.6	22.2	300.0
60.8	66.4	72.4	78.0	83.8	89.4	95.2	201.0	06.8	12.4	18.2	24.0	29.6	10
65.8	71.8	77.6	83.6	89.4	95.4	201.6	07.6	13.6	19.4	25.2	31.2	37.0	20
171.0	177.0	183.2	189.4	195.4	201.8	207.8	214.0	220.0	226.2	232.2	238.4	244.4	30
76.2	82.6	88.8	95.2	201.6	07.8	14.2	20.4	26.7	33.2	39.4	45.6	52.0	40
81.6	88.0	94.6	201.0	07.6	14.0	20.4	26.8	33.4	40.0	46.4	52.8	59.2	350.0
86.8	93.2	200.0	06.6	13.6	22.2	26.8	33.6	40.0	46.6	53.4	60.2	66.8	60
92.0	98.8	05.6	12.4	19.2	26.4	33.0	39.8	46.8	53.6	60.4	67.4	74.2	70
197.2	204.2	211.2	218.4	225.6	232.2	239.4	246.4	253.4	260.4	267.6	274.6	281.6	80
202.4	09.6	16.8	24.0	31.2	38.4	45.8	52.8	60.2	67.6	74.4	81.8	89.0	90
07.4	14.8	22.2	29.6	37.0	44.4	51.8	59.2	66.6	74.0	81.4	88.8	96.2	400.0

TABLE 41—*Concluded*

DISTANCE HORIZONTAL   SUM OF AREAS VERTICAL   QUANTITIES IN CUBIC YARDS

41	42	43	44	45	46	47	48	49	50	75	100		D'ubl Areas
57.7	59.2	60.6	61.9	63.4	64.8	66.2	67.6	69.0	70.4	105.7	140.7	—	76.0
9.2	60.7	2.1	3.6	5.0	6.4	7.8	9.3	70.7	2.3	08.4	44.4	—	8.0
60.8	2.2	3.7	5.2	6.7	8.2	9.7	71.2	2.6	4.1	11.2	48.1	—	80.0
2.2	3.8	5.3	6.8	8.3	9.8	71.4	2.9	4.4	5.9	14.0	51.8	—	2
3.8	5.4	6.9	8.4	70.0	71.6	3.2	4.7	6.2	7.8	16.8	55.5	—	4
65.3	66.8	68.4	70.1	71.7	73.3	74.8	76.4	78.0	79.6	119.5	159.2	—	6
6.8	8.4	70.1	1.7	3.4	5.0	6.6	8.3	9.8	81.5	22.3	63.0	—	8
8.4	70.0	1.7	3.3	5.0	6.7	8.4	80.0	81.7	3.4	25.1	66.7	—	90.0
9.8	1.6	3.3	4.9	6.7	8.4	80.1	1.8	3.5	5.2	27.9	70.6	—	2
71.4	3.2	4.8	6.6	8.4	80.2	1.9	3.6	5.3	7.1	30.7	74.1	—	4
72.8	74.7	76.4	78.2	80.0	81.8	83.6	85.3	97.1	88.9	133.4	177.7	—	6
4.4	6.3	8.1	9.9	1.7	3.5	5.3	7.2	8.9	90.8	36.2	81.6	—	8
5.9	7.7	9.7	81.4	3.3	5.2	7.0	8.8	90.7	2.6	38.9	85.1	—	100.0
9.8	81.7	83.6	5.6	7.5	9.4	91.4	93.4	95.3	7.2	45.9	94.4	—	05
83.5	5.6	7.6	9.6	91.7	93.7	5.7	7.8	9.8	101.9	52.8	203.7	—	10
87.3	89.4	91.6	93.7	95.8	97.9	100.1	102.2	104.4	106.5	159.8	212.9	—	15
91.2	93.4	5.6	7.8	100.0	102.2	04.5	06.7	08.9	11.8	66.7	22.2	—	20
5.0	7.3	9.7	101.9	04.2	06.5	08.9	11.2	13.5	15.6	73.7	31.4	—	125.0
8.8	101.2	103.6	05.9	08.4	10.7	13.1	15.5	17.9	20.2	80.5	40.7	—	30
02.5	05.0	07.5	10.0	12.5	15.0	17.5	20.0	22.5	25.0	87.5	50.0	—	35
06.3	108.9	111.5	114.2	116.7	119.3	121.9	124.4	127.1	129.8	194.5	259.2	—	40
11.2	12.9	15.5	18.2	20.8	23.6	26.2	28.9	31.7	34.3	201.5	68.5	—	45
14.0	16.7	19.5	22.3	25.0	27.8	30.6	33.4	36.2	38.9	08.5	77.7	—	150.0
17.8	20.6	23.5	26.3	29.2	32.1	34.9	37.8	40.8	43.6	15.4	87.0	—	55
1.5	24.5	27.4	30.4	33.4	36.4	39.4	42.3	45.2	48.2	22.4	96.3	—	60
5.3	128.4	131.5	134.4	137.6	140.6	143.8	146.8	149.8	152.8	229.3	305.5	—	65
9.1	32.3	35.4	38.5	41.7	44.9	48.0	51.2	54.3	57.4	36.2	14.8	—	70
2.9	36.1	39.4	42.5	45.8	49.0	52.2	55.5	58.8	62.0	43.0	24.0	—	175.0
6.8	40.0	43.4	46.8	50.0	53.4	56.8	60.0	63.4	66.8	50.0	33.3	—	80
0.5	43.9	47.4	50.8	54.2	57.7	61.0	64.5	67.9	71.4	56.9	42.6	—	85
4.4	147.8	151.4	154.9	158.4	161.9	165.4	168.9	172.4	176.0	263.9	351.8	—	90
8.1	51.8	55.3	58.9	62.5	66.2	69.8	73.4	77.0	80.5	70.8	61.1	—	95
1.8	55.6	59.3	63.0	66.8	70.4	74.1	77.8	81.4	85.2	77.7	70.3	—	200.0
0.5	63.4	67.3	71.1	75.0	78.9	82.8	86.7	90.5	94.5	91.6	88.9	—	10
7.0	71.2	75.2	79.3	83.4	87.5	91.5	95.6	99.7	203.7	305.5	407.4	—	20
1.7	178.9	183.3	187.5	191.8	196.0	200.1	204.4	208.8	213.0	319.4	425.9	—	30
.2	86.8	91.1	95.5	200.0	204.5	08.8	13.3	17.8	22.2	33.3	44.4	—	40
.8	94.5	99.0	203.7	08.3	13.0	17.5	22.2	26.8	31.5	47.1	62.9	—	250.0
.4	202.3	207.0	11.9	16.6	21.6	26.3	31.1	36.0	40.8	61.0	81.5	—	60
.0	10.0	15.0	20.0	25.0	230.0	35.0	40.0	45.0	50.0	75.0	500.0	—	70
.7	217.8	223.0	228.2	233.3	238.6	243.7	248.9	254.1	259.2	388.7	518.5	—	80
.2	25.6	30.9	36.3	41.7	47.1	52.4	57.8	63.2	68.5	402.7	37.0	—	90
.8	33.4	38.9	44.5	50.0	55.6	61.1	66.7	72.3	77.8	16.5	55.5	—	300.0
.4	41.2	46.9	52.6	58.3	64.2	69.8	75.6	81.3	87.0	30.4	74.0	—	10
0	49.0	54.8	60.8	66.7	72.7	78.5	84.4	90.4	96.3	44.3	92.6	—	20
6	256.7	262.8	268.9	275.0	281.2	287.2	293.3	299.5	305.5	458.2	611.0	—	30
2	64.5	70.7	77.1	83.3	89.7	95.9	302.2	308.5	14.8	72.1	29.6	—	40
7	72.3	78.7	85.2	91.7	98.2	304.6	11.1	17.6	24.1	85.9	48.1	—	350.0
3	80.1	86.7	93.4	300.0	306.8	13.3	20.0	26.7	33.0	99.8	66.0	—	60
[illegible]	87.9	94.6	301.5	08.3	15.3	22.0	28.9	35.8	42.6	513.7	85.2	—	70
5	295.6	302.6	309.7	316.7	323.8	330.7	337.8	344.8	351.8	527.6	703.6	—	80
[illegible]	303.4	10.5	17.8	20.0	32.3	339.4	46.7	53.9	61.1	41.5	22.2	—	90
[illegible]	11.1	18.5	25.9	33.3	40.7	48.1	55.5	62.9	70.3	55.5	40.6	—	400.0

TABLE 42. CONVERSION TABLE, LINEAL FEET TO MILES

1 to 9		10–90		100–900		1000–9000		10,000–90,000	
Feet	Miles	Feet	Miles	Feet	Miles	Feet	Miles	Feet	Miles
1	0.00019	10	0.00189	100	0.01894	1000	0.18939	10,000	1.8939
2	0.00038	20	0.00379	200	0.03788	2000	0.37879	20,000	3.7879
3	0.00057	30	0.00568	300	0.05682	3000	0.56818	30,000	5.6818
4	0.00076	40	0.00758	400	0.07576	4000	0.75758	40,000	7.5758
5	0.00095	50	0.00947	500	0.09470	5000	0.94697	50,000	9.4697
6	0.00114	60	0.01136	600	0.11364	6000	1.13636	60,000	11.3636
7	0.00132	70	0.01326	700	0.13258	7000	1.32576	70,000	13.2576
8	0.00152	80	0.01515	800	0.15152	8000	1.51515	80,000	15.1515
9	0.00171	90	0.01705	900	0.17046	9000	1.70455	90,000	17.0455

Overhaul.—If dirt must be hauled more than a stated distance 'free haul) to place it in fill, the additional distance is called over-iaul and is paid for at an agreed rate; the amount of overhaul is :stimated as the (number of cubic yards that have to be overhauled) × (the distance beyond the free haul expressed in stations, that is ınits of 100 ft.). That is, if 20 cu. yd. had to be hauled 3000 ft. vhen the free haul was 2000 ft., the overhaul would be expressed .s 10 stations × 20 yd.

Overhaul is to be avoided if possible, as it is a source of dispute ›etween Contractor and Engineer. Where necessary it can often ›e computed from an inspection of the earthworks computation heets. If the cut from which the dirt is drawn is short and well lefined and the fill to which it is taken is likewise well defined, the ›osition of the centers of gravity of both cut and fill can be located ufficiently close by inspection; however, if two or three cuts are auled to one fill or one cut to more than one fill, the amount and :ngth of overhaul can only be determined with accuracy by means f a mass diagram.

In Fig. 132 an earthwork chart is given which was prepared for ıe Batavia-Buffalo road, State Route 6, Sections 10 and 11. 'his chart gives amount, location, direction, and length of haul ›r excavation at a glance, and as an example of overhaul has :een illustrated on the diagram this will indicate the method.

Explanation of Fig. 132, page 541.—1. The horizontal scale rep-:sents stations along road: in this case 5 stations or 500 ft. to ıe inch.

2. The vertical scale represents the algebraic sum of the exca-ıtion and embankment on whose vertical the amount is plotted. ı this case 200 cu. yd. to the inch.

3. Reading from left to right, all ascending lines indicate amount ıd location of excavation; all descending lines indicate amount ıd location of embankment.

4. All embankment quantities in each balancing section were ultiplied by the factor written above that section as "Balance ;ed."

5. The excavation and embankment quantities at each station :re added together algebraically, after the embankment quantities .d been increased as specified; the algebraic sum so obtained was en added algebraically to the sum similarly obtained from pre-ɔus sections.

6. This diagram indicates the amount of material that should excavated or deposited at each station.

7. The diagram indicates the direction of haul.

8. To compute overhaul consider the section *A B C D E A*. ppose free haul is to be 500 ft. Find where a line 500 ft. long ll fit the section. *B D* is such a line. The material above *B D* ll be hauled free.

On material *A B* there will be paid overhaul. The average .tance the material *A B* will be hauled will be the distance :ween the centers of gravity of *A B* and *D E* respectively.

Let X represent that distance. Then X minus 500 ft. equals the average length of overhaul.

9. The overhaul can also be computed from the area of the section *A B D E A*; this area represents the product of the material excavated in yards and the distance hauled. Find the area of the section *A B D E A* by a planimeter or otherwise. This area will be expressed as yard stations, and when divided by the ordinate *G B* in cubic yards will give the length of haul in stations.

Suppose the area *A B D E A* equals 2.5 square inches. Each square inch represents 200 cu. yd. × 5 stations, or 1000 sta. yd. Therefore, an area of 2.5 square inches would represent 2500 sta. yd. According to the diagram the total amount of dirt hauled equals 280 cu. yd. as measured on the ordinate *GB*. Therefore the average haul for this 280 cu. yd. equals $\frac{2500 \text{ sta. yd.}}{280 \text{ cu. yd.}} = 8.9$ stations.

The free haul equals 500 feet, or 5 stations, therefore the overhaul equals $8.9 - 5 = 3.9$ stations. The amount of overhaul equals 280 cu. yd. $\times\ 3.9 = 1092$ sta. yd.

TABLE 43.[1] GIVING THE NUMBER OF POUNDS OF STONE PER 100 FEET OF ROAD FOR DIFFERENT DEPTHS OF LOOSE SPREAD AND DIFFERENT WEIGHTS OF STONE

12-FOOT ROAD

Weight of 1 cu. yd. Stone, Loose Measure	Depth of Loose Spread				
	2½"	3⅛"	3⅞"	5¼"	6½"
2250	20,800	26,000	32,300	43,700	54,200
2300	21,300	26,600	33,000	44,700	55,300
2350	21,800	27,100	33,700	45,700	56,600
2400	22,200	27,700	34,400	46,700	57,800
2450	22,700	28,200	35,200	47,700	59,000
2500	23,200	28,800	35,900	48,700	60,200
2550	23,600	29,400	36,600	49,600	61,400
2600	24,100	30,000	37,300	50,600	62,600

[1] NOTE. — The quantities in this table are figured by slide rule but are sufficiently close for the purpose to which the table is put.

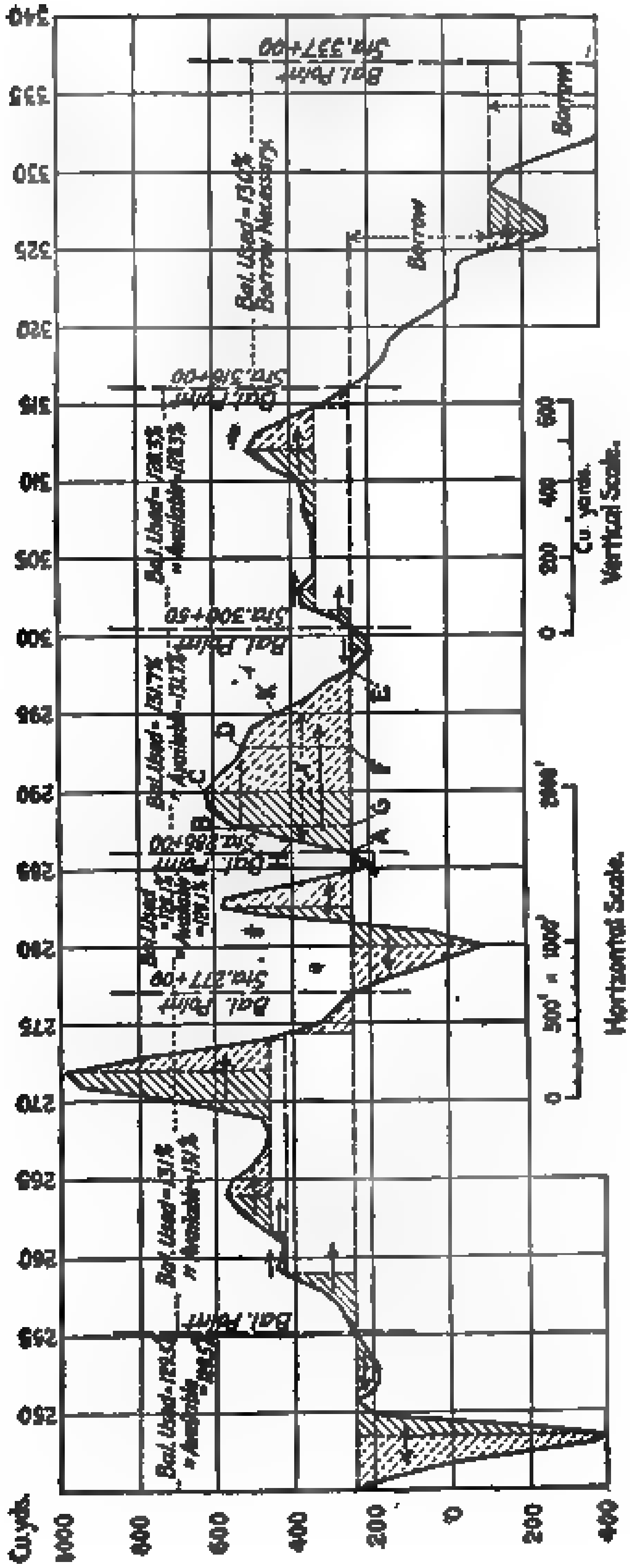

Cu. yds.
Bal. Point
Sta. 337+00
Sta. 318+00
Sta. 300+50
Sta. 286+00
Sta. 277+00
Borrow
Borrow Necessary
Horizontal Scale.
Vertical Scale.
Cu. yds.

FIG. 132.

TABLE 43.—*Concluded*

Weight of 1 cu. yd. Stone, Loose Measure	Depth of Loose Spread				
	$2\frac{1}{2}''$	$3\frac{1}{8}''$	$3\frac{7}{8}''$	$5\frac{1}{4}''$	$6\frac{1}{2}''$
14-FOOT ROAD					
2250	24,300	30,400	37,700	51,000	63,200
2300	24,800	31,000	38,500	52,200	64,600
2350	25,400	31,700	39,300	53,300	66,100
2400	25,900	32,400	40,200	54,400	67,500
2450	26,400	33,000	41,000	55,600	68,900
2500	27,000	33,700	41,800	56,700	70,300
2550	27,600	34,400	42,700	57,800	71,600
2600	28,100	35,100	43,500	59,000	73,000
15-FOOT ROAD					
2250	26,000	32,600	40,400	54,700	67,700
2300	26,600	33,200	41,300	55,900	69,200
2350	27,200	34,000	42,200	57,200	70,800
2400	27,800	34,700	43,100	58,400	72,200
2450	28,400	35,400	44,000	59,600	73,800
2500	29,000	36,100	44,800	60,800	75,200
2550	29,500	36,900	45,800	62,000	76,700
2600	30,100	37,600	46,700	63,200	78,200
16-FOOT ROAD					
2250	27,800	34,700	43,100	58,400	72,300
2300	28,400	35,500	44,000	59,600	73,900
2350	29,000	36,300	45,000	60,900	75,500
2400	29,600	37,000	45,900	62,200	77,200
2450	30,200	37,800	46,900	63,600	78,700
2500	30,900	38,600	47,800	64,900	80,300
2550	31,500	39,400	48,800	66,200	82,000
2600	32,100	40,100	49,800	67,400	83,600

TABLE 44. GIVING THE NUMBER OF CUBIC YARDS OF MACADAM PER 100 FEET OF ROAD FOR DIFFERENT WIDTHS AND DEPTHS

Width of Macadam	Depth							
	2″	2½″	3″	3½″	4″	5″	6″	7″
10′	6.17	7.71	9.26	10.80	12.34	15.43	18.52	21.61
12′	7.41	9.26	11.11	12.96	14.82	18.52	22.22	25.93
14′	8.64	10.80	12.96	15.12	17.28	21.61	25.92	30.25
15′	9.26	11.58	13.89	16.20	18.52	23.16	27.78	32.41
16′	9.88	12.35	14.81	17.28	19.76	24.70	29.63	34.57
18′	11.11	13.90	16.67	19.44	22.22	27.79	33.34	38.89
20′	12.35	15.44	18.52	21.60	24.70	30.87	37.04	43.21
22′	13.58	16.98	20.37	23.76	27.16	33.96	40.74	47.53

TABLE 45

SQUARE YARDS PER 100 FEET AND PER MILE FOR DIFFERENT WIDTH OF SURFACE

Width in Feet	Number of Square Yards		Width in Feet	Number of Square Yards	
	Per 100 Feet	Per Mile		Per 100 Feet	Per Mile
8	88.889	4,693	26	288.889	15,253
10	111.111	5,867	28	311.111	16,427
12	133.333	7,040	30	333.333	17,600
14	155.556	8,213	32	355.556	18,773
15	166.667	8,800	34	377.778	19,947
16	177.778	9,387	36	400.000	21,120
18	200.000	10,560	38	422.222	22,293
20	222.222	11,734	40	444.444	23,466
22	244.444	12,907	42	466.667	24,640
24	266.667	14,080	44	488,889	25,813

The other quantities figured are: length of road in miles. Table 42 converts lineal feet to miles.

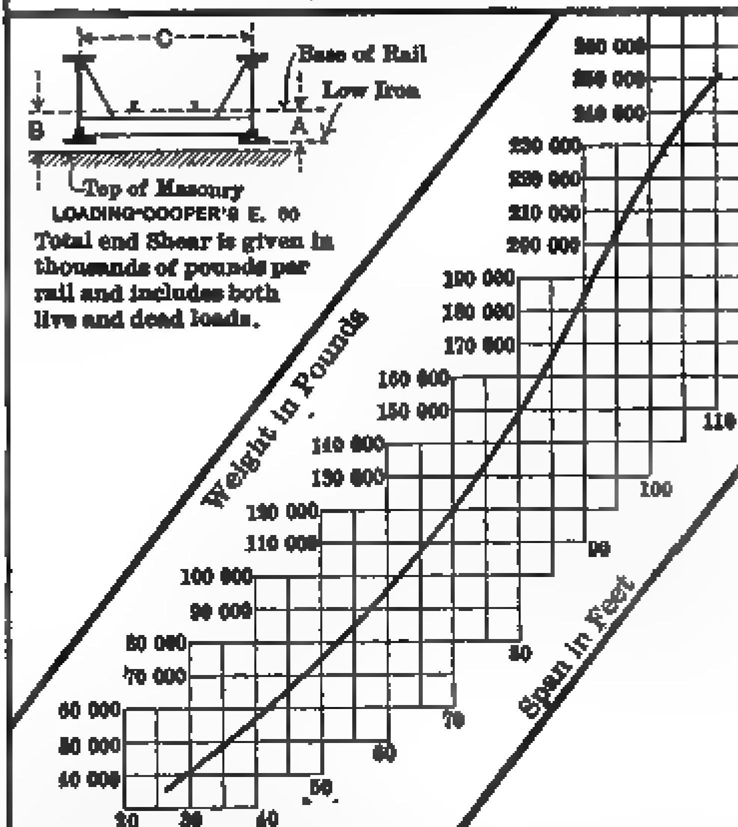
Quantities of macadam, sub-base, concrete paving foundations, square yards of resurfacing, which are simple computations involving length, width, and depth: Tables 43, 44 and 45 can be conveniently used.

Quantities of oil or other surface or penetration treatments, which

feet. For solid floor railroad through girder bridges a clearance of 13.5′ below the bottom of the girder means a distance of from 16.5′ to 17.0′ below the top of the rail.

The tables (pp. 547, 548) are taken from Spofford's "Theory of Structures," and a pamphlet issued by Heath & Milligan, of Chicago. They show the approximate weight of through girder railway bridges with the depth of floor system. They are useful for preliminary estimates of grade-crossing elimination.

THROUGH PLATE GIRDER SPANS, I-BEAM FLOOR
WEIGHTS, DIMENSIONS, ETC.



Span	Total End Sh.	A	B	[illegible]
30 ft.	106.3	2-2″	2-3″	16-0″
35 "	117.1	"	"	16-0
40 "	[illegible]	"	"	17-0
45 "	141.1	2-2¾	2-2¾	17-6
50 "	152.2	"	"	"
55 "	163.1	2-3	2-9	"
60 "	173.3	"	"	"
65 "	186.3	"	"	"
70 "	[illegible]	2-3¾	3-0	"
75 "	212.5	"	3-10¾	"
80 "	[illegible]	"	"	"
85 "	[illegible]	"	"	"
90 "	257.4	"	"	"
95 "	[illegible]	"	"	"
100 "	[illegible]	2-4	"	"
110 "	[illegible]	2-4¼	"	"

Erector's Note:
W= Total weight of one single track span with two light girders.

Span	Weight of one light girder	Weight of one heavy girder	Weight of one floor system
30′ to 50′	.33 W	.30 W	.50 W
55′ " 80′	.27 W	.43 W	.47 W
85′ " 110′	.21 W	.57 W	.38 W

The weights given are for the steel only; the weight of the floor system must be added. For purposes of a rough preliminary estimate of cost the superstructure can be assumed to cost \$80.00 per ton in place including all erection costs.

Where the highway crosses over the railroad a minimum clearance of 21.0′ is used from the top of rail to the bottom of the highway bridge; the span varies with the number of tracks. In determining the length required it is best to get in touch with the railroad engineers.

Alignment at Grade Crossings—New York State Regulations

1. The alignment should be laid out so that approaches are on a tangent which is at least 400 feet long, 200 feet on each side of the crossing. The angle that the highway makes with the railroad should not be less than 60 degrees. The grade of the approaches should not be greater than 6 per cent., and there should be a portion level or nearly so for a distance of not less than 100 feet on each side of the crossing.
2. On the highway within 200 feet of the railroad, on each side, traffic should have a clear view of approaching trains for a distance of 1000 feet. (See Rule 5.)
3. The width of the planked crossing shall not be less than 24 feet, measured at right angles to the center line of the highway. The ends of the pavement should be protected by an edging of stone or concrete placed at a sufficient distance from the ends of the ties to allow for replacing them.
4. A standard danger sign should be placed at each side of the crossing along the highway in a prominent location at least 400 feet from the crossing.
5. When the view of the railroad either way, as required in 2, is less than 1000 feet, or when there is a great deal of traffic on either the highway or railroad, or when vision may be blocked by cars or trains as in the case of a railroad with two or more tracks, a flagman should be employed to warn highway traffic.

Right-of-Way Computations.—The form of traverse computation and closure was shown on page 334.

The areas of rights of way are generally figured by dividing the parcel into rectangles, trapezoids, triangles, sectors, or segments, and figuring these shapes from the formulæ given in Table 70. These areas are checked by planimeter. They are usually figured to the nearest 0.01 acre.

The method of double-meridian distances can, however, be used if desired. The following formula and example are given to illustrate this method. It is not often necessary and is a tedious computation:

The rule is:

Twice the area of the figure is equal to the algebraic sum of the products of the double-meridian distances of each course multiplied by its latitude.

In which the double-meridian distance equals the sum of the meridian distances of the two ends of each course referred to the meridian drawn through the most westerly point of the parcel,

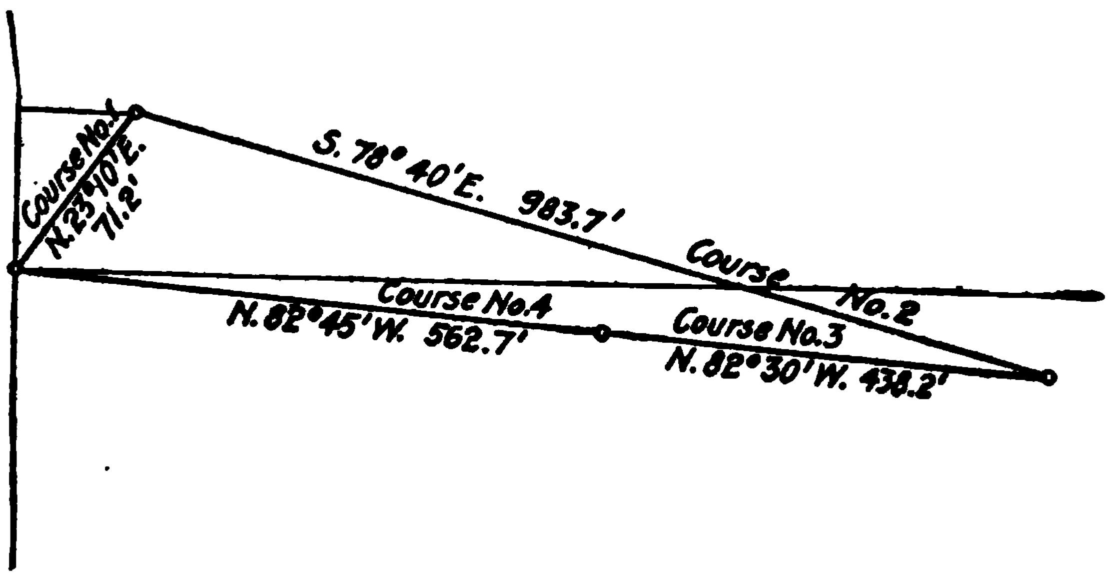
Example of Double-meridian distance Area Computation of the Parcel shown in Fig. 69, page 334. And figure on page 551.

Course Number	Bearing	Dist.	N	S	E	W	Lat.	D. M. D.	+ Areas	− Areas
1	N 23° 10′ E . . .	71.2	65.4	—	28.0	—	+ 65.4	28.0	1,831	—
2	S 78° 40′ E . . .	983.7	—	193.3	964.5	—	− 193.3	1020.5	—	197,263
3	N 82° 30′ W . . .	438.2	57.2	—	—	434.5	+ 57.2	1550.5	88,688	—
4	N 82° 45′ W . . .	562.7	71.0	—	—	558.2	+ 71.0	558.2	39,632	—

197,263 sq. ft. − 130,151 sq. ft. = 67,112 sq. ft.
This equals twice the area of the parcel.

$$\text{Area of parcel} = \frac{67112}{2 \times 43{,}560} = 0.770 \text{ acres.}$$

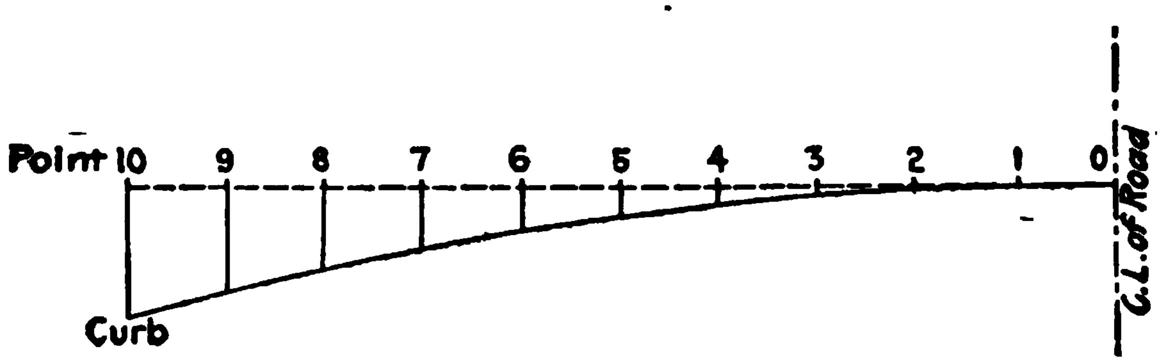
and the latitude of each course is reckoned as plus if the course runs north and minus if it runs south. Take as an example the right of way parcel shown in Fig. 69, page 334, for which the traverse has been figured and refer the meridian distances to the meridian drawn through the corner 3.1′ distant from station 194 + 71.7.



Parabolic Crowns for Pavements.—It is often convenient to have the following data on parabolic crown ordinates in making templets for pavement work.

Divide the distance from the center of the road to the curb or edging into ten equal parts and call the total crown 1.0; the distance down to the surface of the pavement from the crown elevation at each of these ten points expressed in terms of the total crown will be

Center of Road, point No.	0	0.00
	1	0.01
	2	0.04
	3	0.09
	4	0.16
	5	0.25
	6	0.36
	7	0.49
	8	0.64
	9	0.81
Curb point	10	1.00



Summary of Points to be Considered in Making an Economical Design

Justifiable economy in grading is largely limited to the intermediate grades and to variations in the cross-sections. A well-designed road in these particulars may easily save $700 to $900 per mile over a careless design.

Economy in widths of hard paving is attained by the selection of a width suitable to each particular road or part of road. A uniform width of 16 ft. for all roads is unnecessary and a waste of money both in first cost and in maintenance and renewal. For class I and II traffic nothing less than 18′ or 15′ should be considered; for class III and IV the widths may vary from 10′ up. The cost per foot width per mile for different types is approx. as follows:

Type of Road	First Cost per foot width per mile
Brick	$1200
Asphalt	1100
Concrete	950
Bituminous Macadam	750
Waterbound "	650

Economy in foundations is limited to utilizing local materials to their best advantage with short hauls.

Economy in top courses lies in the selection of the cheapest type suitable to the traffic conditions and the use of the minimum thickness.

Economy in maintenance is attained by preventing rather than by repairing damage.

TABLE 46. GALLONS PER 100′ OF ROAD FOR DIFFERENT WIDTHS AND RATES OF APPLICATION

Width in Feet	Number of Gallons to the Square Yard											
	0.1	0.2	0.25	0.3	0.33⅓	0.4	0.5	0.6	0.66⅔	0.7	0.8	0.9
8	8.89	17.78	22.22	26.67	29.63	35.56	44.44	53.33	59.26	62.22	71.11	80.00
10	11.11	22.22	27.77	33.33	37.04	44.44	55.56	66.67	74.08	77.78	88.89	100.00
12	13.33	26.67	33.33	40.00	44.45	53.33	66.67	80.00	88.89	93.33	106.67	120.00
14	15.56	31.11	38.89	46.67	51.85	62.22	77.78	93.33	103.71	108.89	124.44	140.00
15	16.67	33.33	41.67	50.00	55.56	66.67	83.33	100.00	111.11	116.67	133.33	150.00
16	17.78	35.56	44.44	53.33	59.26	71.11	88.89	106.67	118.52	124.44	142.22	160.00
18	20.00	40.00	50.00	60.00	66.67	80.00	100.00	120.00	133.33	140.00	160.00	180.00
20	22.22	44.44	55.56	66.67	74.07	88.89	111.11	133.33	148.15	155.56	177.78	200.00
22	24.44	48.89	61.11	73.33	81.48	97.78	122.22	146.67	162.97	171.11	195.56	220.00
24	26.67	53.33	66.67	80.00	88.89	106.67	133.33	160.00	177.78	186.67	213.33	240.00
26	28.89	57.78	72.22	86.67	96.29	115.56	144.44	173.33	192.60	202.22	231.11	260.00
28	31.11	62.22	77.78	93.33	103.70	124.44	155.56	186.67	207.41	217.78	248.89	280.00
30	33.33	66.67	83.33	100.00	111.11	133.33	166.67	200.00	222.22	233.33	266.67	300.00
32	35.56	71.11	88.89	106.67	118.51	142.22	177.78	213.33	237.04	248.89	284.44	320.00
34	37.78	75.56	94.44	113.33	125.92	151.11	188.89	226.67	251.86	264.44	302.22	340.00
36	40.00	80.00	100.00	120.00	133.33	160.00	200.00	240.00	266.67	280.00	320.00	360.00
38	41.11	84.44	105.56	126.67	140.73	168.89	211.11	253.33	281.49	295.56	337.78	380.00
40	43.33	88.89	111.11	133.33	148.14	177.78	222.22	266.67	296.30	311.11	355.56	400.00
42	45.56	93.33	116.67	140.00	155.55	186.67	233.33	280.00	311.11	326.67	373.33	420.00
44	48.89	97.77	122.22	146.67	162.96	195.56	244.44	293.33	325.92	342.22	391.11	440.00

GALLONS PER 100′ OF ROAD FOR DIFFERENT WIDTHS AND RATES OF APPLICATION—*Continued*

Width in Feet	Number of Gallons to the Square Yard											
	1.0	1.1	1.2	1.25	1.3	1.33⅓	1.4	1.5	1.6	1.66⅔	1.7	1.8
8	88.89	97.78	106.67	111.11	115.56	118.52	124.44	133.33	142.22	148.15	151.11	160.00
10	111.11	122.22	133.33	138.89	144.44	148.15	155.56	166.67	177.78	185.19	188.89	200.00
12	133.33	146.67	160.00	166.67	173.33	177.78	186.67	200.00	213.33	222.22	226.67	240.00
14	155.56	171.11	186.67	194.44	202.22	207.41	217.78	233.33	248.89	259.26	264.44	280.00
15	166.67	183.33	200.00	208.33	216.67	222.22	233.33	250.00	266.67	277.77	283.33	300.00
16	177.78	195.56	213.33	222.22	231.11	237.04	248.89	266.67	284.44	296.30	302.22	320.00
18	200.00	220.00	240.00	250.00	260.00	266.67	280.00	300.00	320.00	333.33	340.00	360.00
20	222.22	244.44	266.67	277.78	288.89	296.30	311.11	333.33	355.56	370.37	377.78	400.00
22	244.44	268.89	293.33	305.56	317.78	325.93	342.22	366.67	391.11	407.41	415.56	440.00
24	266.67	293.33	320.00	333.33	346.67	355.56	373.33	400.00	426.67	444.44	453.33	480.00
26	288.89	317.78	346.67	361.11	375.56	385.19	404.44	433.33	462.22	481.48	491.11	520.00
28	311.11	342.22	373.33	388.81	404.44	414.82	435.56	466.67	497.78	581.51	528.89	560.00
30	333.33	366.67	400.00	416.67	433.33	444.44	466.67	500.00	533.33	555.55	566.67	600.00
32	355.56	391.11	426.67	444.44	462.22	474.08	497.78	533.33	568.89	592.58	604.44	640.00
34	377.78	415.56	453.33	472.22	491.11	503.71	528.89	566.67	604.44	629.62	642.22	680.00
36	400.00	440.00	480.00	500.00	520.00	533.33	560.00	600.00	640.00	666.67	680.00	720.00
38	422.22	464.44	506.67	527.78	548.89	562.97	591.11	633.33	675.56	703.70	717.78	760.00
40	444.44	488.89	533.33	555.56	577.78	592.60	622.22	666.67	711.11	740.73	755.56	800.00
42	466.67	513.33	560.00	583.33	606.67	622.22	653.33	700.00	746.67	777.78	793.33	840.00
44	488.89	537.78	586.67	611.11	635.56	651.85	684.44	733.33	782.22	814.81	831.11	880.00

1

Gauge	Size Mesh	Weight in Pounds per Sq. Ft.
10	3½″ × 7″	0.68
12	3½″ × 7″	0.54
10	2½″ × 5″	0.86
12	2½″ × 5″	0.68
14	2½″ × 5″	0.48
16	2½″ × 5″	0.37
16	1½″ × 3″	0.40
16	1″ × 2″	0.50
15	1″ × 2″	0.57
14	1″ × 2″	0.64
13	1″ × 2″	0.78

2

Mesh	Gauge (Stubs)	Strand Standard or Extra	Section Area per Foot of Width	Weight per Sq. Ft.	Size of Standard Sheets	No. of Sheets in Bundle	No. of Sq. Ft. in 8′ Bundle
½″	No. 18	Standard	0.209	.74	3′ or 6′ × 8′	5	120
¾″	13	"	0.225	.80	6′ × 8′ or 12′	5	240
1½″	12	"	0.207	.70	4′ × 8′ or 12′	5	160
2″	12	"	0.166	.56	5′ × 8′ or 12′	5	200
3″	16	"	0.083	.28	6′ × 8′ or 12′	10	480
3″	10	Light	0.148	.50	6′ × 8′ or 12′	5	240
3″	10	Standard	0.178	.60	6′ × 8′ or 12′	5	240
3″	10	Heavy	0.267	.90	4′ × 8′ or 12′	5	160
3″	10	Ex "	0.356	1.20	6′ × 8′ or 12′	3	144
3″	6	Standard	0.400	1.38	5′ × 8′ or 12′	3	120
3″	6	Heavy	0.600	2.07	5′ × 8′ or 12′	3	120
4″	16	Old Style	0.093	.42	4½′ × 8′ or 9′	6	216
6″	4	Standard	0.245	.84	5′ × 8′ or 12′	5	200

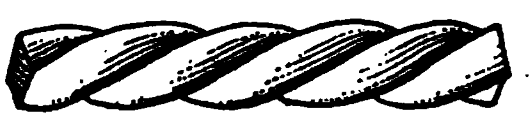
U. S. Standard Gauge	Size Mesh	Sectional Area in Sq. In. per Foot of Width	Weight in Pounds per Sq. Ft.
18	½″ × 1½″	0.203	0.69
12	¾″ × 2″	0.253	0.86
12	1½″ × 3″	0.188	0.64
16	2½″ × 6″	0.087	0.29
16	3″ × 8″	0.130	0.44
16	3″ × 8″	0.059	0.20
12	3″ × 8″	0.109	0.37
10	3″ × 8″	0.162	0.55
10	3″ × 8″	0.243	0.81
10	3″ × 8″	0.324	1.07
7	3″ × 8″	0.400	1.36
4	6″ × 12″	0.245	0.84
4	6″ × 12″	0.368	1.26

NOTE. — Expanded metal for small culverts is generally specified as weighing a certain number of pounds per square foot and having a mesh approximately the size shown on the plans.

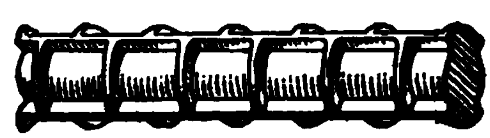
TABLE 48. TABLE OF ROUND AND SQUARE BAR WEIGHTS

Round Bars			Plain Square Bars and Twisted Square Bars		
Diameter	Area	Weight	Dimension	Area	Weight
$\frac{1}{4}$	.0491	.167	$\frac{1}{4}$	.0625	.212
$\frac{5}{16}$	.0767	.261	$\frac{5}{16}$	.0977	.332
$\frac{3}{8}$	.1104	.376	$\frac{3}{8}$	.1406	.478
$\frac{7}{16}$	.1503	.511	$\frac{7}{16}$	.1914	.651
$\frac{1}{2}$	.1963	.668	$\frac{1}{2}$	.2500	.850
$\frac{9}{16}$	.2485	.845	$\frac{9}{16}$	.3164	1.076
$\frac{5}{8}$	.3068	1.043	$\frac{5}{8}$	.3906	1.328
$\frac{11}{16}$	.3712	1.262	$\frac{11}{16}$	.4727	1.607
$\frac{3}{4}$	.4418	1.502	$\frac{3}{4}$	.5625	1.913
$\frac{13}{16}$	.5185	1.763	$\frac{13}{16}$	.6602	2.245
$\frac{7}{8}$	.6013	2.044	$\frac{7}{8}$	.7656	2.603
$\frac{15}{16}$	.6903	2.347	$\frac{15}{16}$	.8789	2.988
1	.7854	2.670	1	1.0000	3.400
$1\frac{1}{8}$	.9940	3.380	$1\frac{1}{8}$	1.2656	4.303
$1\frac{1}{4}$	1.2272	4.172	$1\frac{1}{4}$	1.5625	5.313
$1\frac{3}{8}$	1.4849	5.049	$1\frac{3}{8}$	1.8906	6.428
$1\frac{1}{2}$	1.7671	6.008	$1\frac{1}{2}$	2.2500	7.650

Diameters expressed in inches. Areas expressed in square inches.
Weights expressed in pounds per foot of length.
The twisted square bar is known as the Ransome Bar.



Ransome Bar.



Kahn Cup Bar.

Corrugated Bars.

Diamond Bar.

Thacher Bar.

TABLE 48. *Continued*

Nominal Size of Bar	Weight and Net Sectional Areas of Different Reinforcing Bars									
	Kahn Cup Bar		Twisted Lug Bar		Corrugated Bars		Thacher Bar		Diamond Bar	
	Area	Weight	Area	Weight	Area	Weight	Area	Weight	Area	Weight
$\frac{1}{4}$			0.0625	0.222			0.047	0.16	0.062	0.22
$\frac{3}{8}$	0.1406	0.502	0.1406	0.492			0.100	0.34	0.141	0.48
$\frac{1}{2}$	0.2500	0.893	0.2500	0.870	0.25	0.86	0.18	0.61	0.250	0.85
$\frac{5}{8}$	0.3906	1.394	0.3906	1.350			0.28	0.95	0.391	1.33
$\frac{3}{4}$	0.5625	2.008	0.5625	1.940	0.56	1.93	0.41	1.39	0.563	1.91
$\frac{7}{8}$	0.7656	2.733	0.7656	2.640	0.77	2.65	0.55	1.87	0.766	2.60
1	1.0000	3.570	1.0000	3.450	1.00	3.45	0.71	2.41	1.000	3.40
$1\frac{1}{8}$	1.2656	4.518	1.2656	4.350			0.90	3.06		
$1\frac{1}{4}$	1.5625	5.578	1.5625	5.370	1.56	5.36	1.10	3.74	1.563	5.31

TABLE 49. STANDARD THICKNESS AND WEIGHTS OF CAST-IRON PIPE ADOPTED MAY 12, 1908 BY AMERICAN WATER-WORKS ASSOCIATION

Nominal Inside Diameter Inches	LIGHT 100 Foot Head			MEDIUM 200 Foot Head			HEAVY 300 Foot Head			EXTRA HEAVY 400 Foot Head		
	43 Pounds Pressure			86 Pounds Pressure			130 Pounds Pressure			173 Pounds Pressure		
	Thick-ness	Weight per		Thick-ness	Weight per		Thick-ness	Weight per		Thick-ness	Weight per	
		Foot	Length		Foot	Length		Foot	Length		Foot	Length
3	.39	14.5	175	.42	16.2	194	.45	17.1	205	.48	18.0	216
4	.42	20.0	240	.45	21.7	260	.48	23.3	280	.52	25.0	300
6	.44	30.8	370	.48	33.3	400	.51	35.8	430	.55	38.3	460
8	.46	42.9	515	.51	47.5	570	.56	52.1	625	.60	55.8	670
10	.50	57.1	685	.57	63.8	765	.62	70.8	850	.68	76.7	920
12	.54	72.5	870	.62	82.1	985	.68	91.7	1,100	.75	100.0	1,200
14	.57	89.6	1,075	.66	102.5	1,230	.74	116.7	1,400	.82	129.2	1,550
16	.60	108.3	1,300	.70	125.0	1,500	.80	143.8	1,725	.89	158.3	1,900
18	.64	129.2	1,550	.75	150.0	1,800	.87	175.0	2,100	.96	191.7	2,300
20	.67	150.0	1,800	.80	175.0	2,100	.92	208.3	2,500	1.03	229.2	2,750
24	.76	204.2	2,450	.89	233.3	2,800	1.04	279.2	3,350	1.16	306.7	3,680
30	.88	291.7	3,500	1.03	333.3	4,000	1.20	400.0	4,800	1.37	450.0	5,400
36	.99	391.7	4,700	1.15	454.2	5,450	1.36	545.8	6,550	1.58	625.0	7,500
42	1.10	512.5	6,150	1.28	591.7	7,100	1.54	716.7	8,600	1.78	825.0	9,900
48	1.26	666.7	8,000	1.42	750.0	9,000	1.71	908.3	10,900	1.96	1,050.0	12,600

TABLE 50.—WEIGHT OF CORRUGATED METAL PIPE

Diameter	Gage of Metal	Weight per Foot	Freight Classification	
			Riveted	Nestable
12″	16	11 lb.	2	3
15″	16	13½ "	2	3
18″	16	16 "	2	3
21″	16	18 "	2	3
24″	16	22 "	2	3
30″	14	32 "	1	3
36″	14	37 "	1	3
42″	14	44 "	1	3
48″	14	51 "	1	3

NOTE.—In carload lots the freight classification is No. 4 for Riveted pipe, No. 5 for Nestable pipe.

TABLE 50A.—APPROXIMATE WEIGHTS, DIMENSIONS, ETC. OF STANDARD SEWER PIPE

Calibre, In.	Price per Foot	Weight per Foot, Lbs.	Depth of Socket, In.	Annular Space, In.	Thickness, In.
3	$ 0.30	7	1½	¼	½
4	0 30	9	1⅝	⅜	½
5	0 45	12	1¾	⅜	⅝
6	0 45	15	1⅞	⅜	⅝
8	0 70	23	2	⅜	¾
9	1 05	28	2	⅜	13–16
10	1.05	35	2⅛	⅜	⅞
12	1 35	45	2¼	½	1
15	1 80	60	2½	½	1⅛
18	2 50	85	2¾	½	1¼
20	3 00	100	3	½	1⅜
22	4.00	130	3	½	1⅝
24	4 50	140	3¼	½	1⅝
27	6.50	224	4	¾	2
30	7 20	252	4	¾	2⅛
33	9.00	310	5	1¼	2¼
36	10.25	350	5	1¼	2½

DOUBLE STRENGTH PIPE

Calibre, In.	Price per Foot	Weight per Foot, Lbs.	Depth of Socket, In.	Annular Space, In.	Thickness, In.
15	$1.80	75	2½	½	1¼
18	2.50	118	2¾	½	1½
20	3.00	138	3	½	1⅜
22	4 00	157	3	½	1⅝
24	4.50	190	3¼	½	2
27	6.50	265	4	¾	2¼
30	7.20	290	4	¾	2½
33	9.00	335	5	1¼	2⅝
36	10 25	375	5	1¼	2¾

Discount about 74% off Standard.
" " 68% off Double Strength.

TABLE 51. PROPERTIES OF CAMBRIA STANDARD I-BEAMS

Depth of Beam	Weight per Foot	Area of Section	Thickness of Web	Width of Flange	For Fiber Stress of 12,500 lbs. per Sq. In. for Bridges
Inches	Pounds	Sq. Inches	Inch	Inches	Coefficient of Strength
3	5.50	1.63	.17	2.33	13,790
3	6.50	1.91	.26	2.42	14,950
3	7.50	2.21	.36	2.52	16,180
4	7.50	2.21	.19	2.66	24,850
4	8.50	2.50	.26	2.73	26,480
4	9.50	2.79	.34	2.81	28,110
4	10.50	3.09	.41	2.88	29,750
5	9.75	2.87	.21	3.00	40,300
5	12.25	3.60	.36	3.15	45,390
5	14.75	4.34	.50	3.29	50,490
6	12.25	3.61	.23	3.33	60,520
6	14.75	4.34	.35	3.45	66,610
6	17.25	5.07	.47	3.57	72,740
7	15.00	4.42	.25	3.66	86,260
7	17.50	5.15	.35	3.76	93,290
7	20.00	5.88	.46	3.87	100,430
8	18.00	5.33	.27	4.00	118,490
8	20.25	5.96	.35	4.08	125,400
8	22.75	6.69	.44	4.17	133,570
8	25.25	7.43	.53	4.26	141,740
9	21.00	6.31	.29	4.33	157,260
9	25.00	7.35	.41	4.45	170,260
9	30.00	8.82	.57	4.61	188,640
9	35.00	10.29	.73	4.77	207,020
10	25.00	7.37	.31	4.66	203,500
10	30.00	8.82	.45	4.80	223,630
10	35.00	10.29	.60	4.95	244,050
10	40.00	11.76	.75	5.10	264,480
12	31.50	9.26	.35	5.00	299,740
12	35.00	10.29	.44	5.09	317,030
12	40.00	11.76	.56	5.21	341,540

TABLE 51.—*Continued*

Depth of Beam	Weight per Foot	Area of Section	Thickness of Web	Width of Flange	For Fiber Stress of 12,500 lbs. per Sq. In. for Bridges
Inches	Pounds	Sq. Inches	Inch	Inches	Coefficient of Strength
15	42.00	12.48	.41	5.50	490,840
15	45.00	13.24	.46	5.55	506,490
15	50.00	14.71	.56	5.65	537,130
15	55.00	16.18	.66	5.75	567,770
15	60.00	17.65	.75	5.84	598,410
18	55.00	15.93	.46	6.00	736,620
18	60.00	17.65	.56	6.10	779,440
18	65.00	19.12	.64	6.18	816,200
18	70.00	20.59	.72	6.26	852,970
20	65.00	19.08	.50	6.25	974,600
20	70.00	20.59	.58	6.33	1,016,490
20	75.00	22.06	.65	6.40	1,057,340
24	80.00	23.32	.50	7.00	1,449,460
24	85.00	25.00	.57	7.07	1,505,430
24	90.00	26.47	.63	7.13	1,554,450
24	95.00	27.94	.69	7.19	1,603,470
24	100.00	29.41	.75	7.25	1,652,490

Explanation of the coefficient of strength in the above table and examples showing use in practice.

The coefficient of strength for each sized beam represents the maximum uniformly distributed load, in pounds, that will produce a fiber stress not exceeding 12,500 lbs. per sq. inch multiplied by the span in feet.

If the load to be investigated is a concentrated load it must be changed to an equivalent uniform load in order to use the values given. This is done by multiplying the concentrated load by 2.

EXAMPLE: Suppose that it is required to determine the size I-beam that will carry a 40,000 lb. load in the center of a 15′ span and a uniformly distributed load of 20,000 lbs. The coefficient of resistance for the concentrated load will be 2 (40,000) × 15 = 1200000

Uniform load 20,000 × 15 = 300000

1500000

The required beam must have a coefficient of resistance of 1500000 plus the coefficient due to its own weight. A 24″ beam weighing 90 lbs. per foot has a coefficient of 1,554,450.

The beam weighs 90 × 15 = 1,350. The coefficient for the beam weight is 1,350 × 15 = 20,250, which deducted from 1,554,450 gives a coefficient of 1,534,200, which is slightly greater than required and safe.

TABLE 52.—CONDENSED TABLE OF STRENGTH OF WOODEN BEAMS

Based on a very complete table published in the Cambria Steel Handbook to which the reader is referred if he is using much data of this kind.

This tabulation based on factor of safety of 6.

Allowable fiber stress 1200 lb. per square inch.

The loads given are the safe total uniformly distributed loads per inch width of beam for the span noted including the weight of the beam.

This table applies directly to White Oak and Long Leaf Yellow Pine.

For Hemlock use ½ of the load given.

For Douglas Fir, Norway Pine, Cypress, Chestnut and Spruce, use ⅗ of the load given.

NOTE.—The safe concentrated superimposed load is ½ of the total superimposed uniformly distributed load exclusive of the weight of the beam.

For weight of timber see pages 950 and 805.

Span in Feet	Depth of Beam in Inches										
	4″	6″	8″	10″	12″	14″	16″	18″	20″	22″	24″
4	535	1200									
6	355	800	1420								
8	270	600	1070	1670	2400						
10	215	480	850	1330	1920	2610					
12	180	400	710	1110	1600	2180	2840	3600			
14	150	340	610	950	1370	1870	2440	3090	3810		
16	135	300	530	830	1200	1630	2130	2700	3330	4030	4800
18	120	270	480	740	1070	1450	1900	2400	2960	3590	4270
20	105	240	430	670	960	1310	1710	2160	2670	3230	3840
22	95	220	390	610	870	1190	1550	1960	2420	2930	3490
24	90	200	360	560	800	1090	1420	1800	2220	2690	3200
26		185	330	510	740	1000	1310	1660	2050	2480	2950
28		170	305	480	690	930	1220	1540	1900	2300	2740
30		160	285	440	640	870	1140	1440	1780	2150	2560

NOTE.—If a deep beam is used for a shorter span than shown in the table figure the limiting load on the basis of shear along the neutral axis. By the formula

$$W = \frac{4bds}{3}$$

In which W = safe load in pounds uniformly distributed.

d = depth of beam in inches.

b = breadth of beam in inches.

S = allowable shear in the direction of the grain in pounds per square inch.

White pine.................100 lb. per square inch.
Long leaf yellow pine........150 lb. per square inch.
White oak..................200 lb. per square inch.

TABLE 53.

Span in Feet	Depth of Slab in Inches									
	6″	8″	10″	12″	14″	16″	18″	20″	22″	24″
2	3,810									
4	895	1,760	2,810	4,300	5,840					
6	355	725	1,180	1,830	2,500	3,390	4,420			
8	163	365	600	960	1,320	1,810	2,380	2,860	3,570	
10	80	197	340	550	780	1,090	1,440	1,730	2,180	2,670
12	......	100	200	340	490	690	930	1,120	1,420	1,750
14	......	......	110	210	310	450	620	760	970	1,210
16	......	......	......	120	190	300	420	520	680	750
18	......	......	......	......	......	190	280	350	470	610
20	......	......	......	......	......	......	200	230	330	430
22	......	......	......	......	......	......	......	180	220	310
24	......	......	......	......	......	......	......	......	150	210
Resisting moment of slab in ft. lb. per ft. width of slab	1,925	3,770	5,890	8,900	12,030	16,170	20,960	24,940	30,800	37,260
Net area of rods (sq. in.)	0.25	0.25	0.39	0.39	0.56	0.56	0.77	0.77	1.00	1.00
Spacing of rods (in.)	6″	5″	6″	5″	6″	5″	6″	5″	6″	5″
Depth below steel	1.00″	1.00″	1.25″	1.50″	1.50″	1.50″	1.50″	2.00″	2.00″	2.00″
Weight of slab per sq. ft.	77	103	128	154	180	206	232	257	283	310

TABLE 53.—CONDENSED TABLE OF STRENGTH OF REINFORCED CONCRETE SLABS (Free End Supports)

Safe Uniformly distributed superimposed load per square foot of slab for the span noted, exclusive of weight of slab.
Factor of safety 5 which is *very conservative.*
(NOTE.—For factor of safety of 4 add ¼ to the tabular loads.)
Concrete 1 : 2 : 4 mix.

Allowable unit stress in concrete... 500 lb. per square inch.
" " " " steel....14,000 lb. per square inch.

NOTE.—The safe concentrated load is ½ of the total uniformly distributed load.

TABLE 53A.—RECOMMENDED THICKNESS OF CONCRETE SLABS WHEN USED IN HIGHWAY BRIDGES UNDER DIFFERENT DEPTHS OF EARTH OR MACADAM FILL (Conservative Practice)

Span of Slab in Feet	Depth of Fill Over Slab in Feet						
	1′	2′	4′	6′	8′	10′	12′
2	6″	6″	6″	6″	6″	6″	6″
4	7″	7″	7″	7″	7″	7″	7″
6	9″	9″	9″	10″	10″	10″	11″
8	10″	10″	10″	11″	12″	13″	13″
10	12″	12″	13″	14″	15″	16″	17″
12	14″	14″	15″	16″	17″	18″	20″
14	16″	16″	17″	18″	19″	20″	22″
16	18″	18″	19″	20″	22″	24″	
18	20″	20″	22″	23″	24″		
20	22″	22″	23″	24″			

TABLE 54.—CONDENSED TABLE OF STRENGTH OF REINFORCED CONCRETE BEAMS (Free End Supports)

Safe uniformly distributed superimposed load per foot length of beam per inch width of beam, exclusive of weight of beam.

To get the total superimposed load per foot length of the beam multiply the tabular load by the width of beam in inches.

Factor of safety 5 (conservative practice)

Span in Feet	Depth of Beam in Inches						
	12″	18″	24″	30″	36″	42″	48″
6	152	370					
8	80	200	362				
10	46	120	222	370	540	760	
12	28	78	146	247	360	510	690
14	17	52	100	173	255	360	490
16	...	35	70	125	190	270	360
18	...	...	50	92	140	200	280
20	...	...	...	70	110	160	210
25	...	...	...	...	55	80	120
30	...	...	...	...	...	45	70
35	...	...	...	...	...	...	35
Resisting moment of beam in ft. lb. per inch width	740	1,740	3,100	5,030	7,200	10,000	13,300
Area of steel (sq. in.) per inch width	0.066	0.101	0.134	0.171	0.210	0.240	0.278
Distance from steel to bottom of beam	1.5″	1.5″	2.0″	2.0″	2.5″	2.5″	2.5″
Weight of beam 1″ wide, 1′ long	12.8 lb.	19.2 lb.	25.7 lb.	32.1 lb.	38.5 lb.	44.9 lb.	51.4 lb.

TABLE 55.—CONDENSED TABLE OF STRENGTH OF TIMBER UNDER LONG COLUMN ACTION

Based on the Formula of the U. S. Department of Agriculture, ivision of Forestry.

$$P = F \times \frac{700 + 15C}{700 + 15C + C^2}$$

P = ultimate strength in pounds per square inch
F = " crushing strength of timber
$C = \frac{l}{d}$ in which l = length of column in inches
d = least diameter in inches

Safe load per square inch on the basis of a factor of safety of is given below. A factor of safety of 6 is often used in good 'actice.

$\frac{l}{d}$	Safe Load in Pounds per Square Inch			
	White Oak and Long Leaf Yellow Pine	Douglas Fir and Short Leaf Yellow Pine	Red Pine, Spruce Hemlock, Cypress, Chestnut	White Pine and Cedar
5	600	550	480	420
10	560	500	450	390
15	510	450	400	350
20	450	400	360	310
25	400	360	320	280
30	350	320	280	250

)TE.—$\frac{l}{d}$ over 30 is not advised.

(b) THE LOCATION OF NEW ROADS

Detail Instructions compiled by the author for drafting room ›cedure in connection with the design of Mountain Roads.

NOTES FOR DESIGNERS ON THE PREPARATION OF PLANS

[n the preparation of plans, the quickest and easiest methods ich will be sufficiently accurate for the purpose should be used. [n this connection, it should be borne in mind that, as a rule, ıphic methods are to be preferred to computations wherever such :thods are sufficiently accurate. This will probably occur in ıe cases out of ten.

When you consider the methods which will be employed in constructing mountain roads and in staking them out for construction, localized errors in paper locations are not important factors in determining the value of the design.

A localized error in length of one foot or even two feet per one hundred feet on one curve will not materially affect the accuracy of the layout or the quantity of excavation, particularly as these errors tend to balance and they are never cumulative.

A localized error of 0.1 foot or even 0.2 foot on the profile grade line will not destroy the value of the plans or the value of the estimate as it is not cumulative.

Careful graphic methods will not exceed these limits and the average error should be well within the necessary accuracy.

A sample sheet of plan and profile using graphic methods is attached. See page 571. This shows a uniform method of procedure which is to be followed wherever, in your best judgment, the method can be used.

INSTRUCTIONS FOR DRAFTING ROOM

It is necessary in drafting room work to keep all records and computations in as neat and orderly condition as possible.

Have on your desk only as much material as you need for the work you are doing. *Keep the rest in the files.*

At night clean off the tables completely and place your working material either in your table drawers or in the files. Cover tables with cover.

All computations and maps must be marked plainly with the name of the job.

All office computations which will become part of the permanent records are to be made on the forms provided or on letter sized sheets.

The designing chief for each project will be responsible for the following notations on all records.

Name of job on each separate sheet or roll of computations and plans.

Name of computer on each sheet.

Name of checker on each sheet.

The methods employed in all work should be shown in enough detail to make it possible for anyone to check the results.

DRAFTING ROOM SUPPLIES

Tracing cloth, plain, 25″ wide..............	1.7 yd. per mile
Detail paper (36″ wide) (1 lb. = 8′ of 36″ paper)	⅛ lb. " "
Cross-section paper (opaque) (used for profiles) 22″ wide	1.7 yd. per mile
Transparent cross-section paper (22″ wide)	6 " " "
Cross-section sheets (18″ × 24″)........12	sheets per mile

Cost per mile, office supplies, $1.50.

DETAIL INSTRUCTIONS

Mountain Road Design

These instructions have been prepared in detail as many of the ıen have no idea of the order of work or reasonable speeds on the arious parts of the design and in many cases they waste time by eedless work on the rough plans. The cost of design work is ften high on account of the inexperience of the force. By a areful study of these instructions some improvement in speed and ost should be obtained.

Speed of Work.—The following list of reasonable speed is based n a seven hour working day for the average man. If you are not qualing this rate ask the chief draftsman to see if he can help you nd the cause.

General Speed.—Two miles per month per man of completed lans when men are experienced.

About 1¼ miles per month per man when force is not used to oad design.

DETAIL REASONABLE SPEED

ivision of Work			Approximate Miles per Day, per Man
1.	(*a*)	Plotting, checking and inking base line and plotting topography	1.5 miles
	*(*b*)	Base line profile complete	3.0 "
	*(*c*)	Plotting and checking cross-sections	1.0 "
	(*d*)	Inking cross-sections	1.5 "
2.	(*a*)	Trial grade line	7.0 "
	*(*b*)	Projecting grade contour on map	1.5 "
	(*c*)	" final center line	1.0 "
3.	*(*a*)	New center line profile	1.0 "
	*(*b*)	Balanced section profile	1.5 "
	(*c*)	Trial final grade based on balanced profile	1.5 "
	(*d*)	Drawing templets on sections	2.0 "
	(*e*)	Planimeter sections and compute quantities	0.8 "
	*(*f*)	Determine final grade line and balance quantities	0.4 "
	(*g*)	Ink final grade line	7.0 "
4.	(*a*)	Compiling estimate	2.0 "
5.	(*a*)	Tracing plans	0.6 "

NOTE.—*Indicates work that can be done to advantage by two men working together.

Reasonable Cost

General Cost Completed Plans	$40 to $50 per mile with experienced men $80 to $100 " " " inexperienced men

Detail Costs

Based on the following wages:

Designer	$150.00	per month
Draftsman	110.00	" "
Tracers	90.00	" "
Computers	80.00	" "

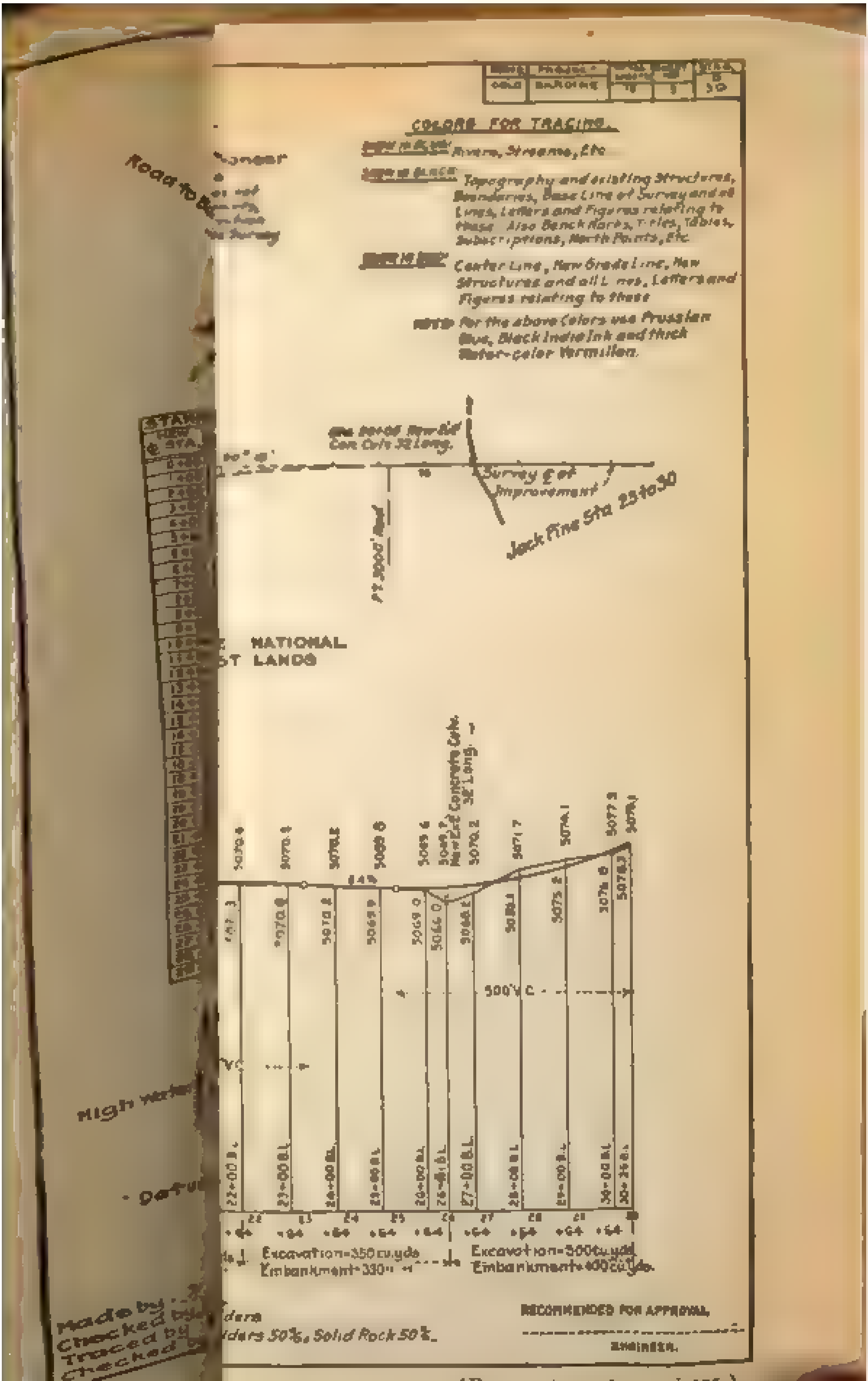
		Cost per Mile
1.	(a) Detailed paper map	$ 2.50
	(b) Base line profile	1.00
	(c) Plotting and checking cross-sections	3.00
	(d) Inking cross-sections	2.00
2.	(a) Laying trial grade	1.00
	(b) Projecting grade contour	3.00
	(c) Projecting final center line	8.00
3.	(a) New center line profile	3.50
	(b) Balanced section profile	4.00
	(c) Trial final grade based on balanced profile	4.00
	(d) Templets drawn on	3.00
	(e) Planimeter and computation of quantities	4.00
	(f) Determine final grade line and balance quantities	10.00
	(g) Ink in final grade line	.50
4.	(a) Compile estimate	3.00
5.	(a) Trace plans	5.00
	Total	$57.50

DETAIL OFFICE DESIGN

MANIPULATION

DETAIL MANIPULATION

General Note.—Get all information on rough plans and profiles needed by the tracer, but do not ink anything not likely to be erased during the design and do not attempt to print notes, etc. A great deal of time is being wasted every day by unnecessary work on the rough plans. We appreciate that good work has been done, but further improvement can be made.



(Between pages 570 and 571.)

Be careful to mark the name of the road on all rolls, sheets, etc., *before* starting work.

We do not expect you to follow these instructions absolutely but the system outlined has been proved in practice and it is expected that you will follow the principles, give the information called for and that you will eliminate useless work.

Preliminary Work:

1. (*a*) **Map.** (See Sample Map.) (One Man working alone.)

The map is drawn on a roll of detail paper 18″ wide.

Scale 1″ = 100′. In exceptionally hard locations use 1″ = 50′

Order of Work

1. Plot base line in pencil (6H) using vernier protractor or tangent method in plotting angles and careful scaling for distances between transit points. Plot bearing of each course from north line drawn through each transit point.

2. Check this plotting.

3. Ink in the base line with a fine solid black line and mark the transit points with small circles.

4. Mark the even stations with a short ink dash and number every fifth station in black ink. Mark station of transit points in black ink.

5. Mark true bearing or azimuth on each course in black ink and check.

6. Show the location of each cross-section by a fine red ink line extending far enough from the base line to reach any center line shift and check. Do this work very carefully as your center line distances will be affected.

7. Plot topography in pencil (4H) making the lines heavy and firm so it can be easily traced without inking. *DO NOT INK.* Write all notes, property names, etc., in large plain long hand. *DO NOT PRINT.* Use 4H pencil with a blunt point so tracer can read easily.

1. (*b*) **Base Line Profile.** (See Sample Profile.)

Use heavy white paper roll 22 inches wide ruled in squares 10 to the inch.

Scales.—Use 1″ = 100′ horizontal or 1″ = 50′ horizontal to agree with the map scale. Use 1″ = 10′ vertical.

Order of Work

1. One man mark even stations in pencil along upper margin. Use 4H pencil with blunt point and make the figures large and distinct, but don't be fussy.

2. (Two men.) One man calling from notes. Other man write in pencil on profile the elevations of base line at even stations and pluses.

Record these elevations in tens, units and tenths. Do not record hundreds and thousands. These can be easily determined by the datum on the profile and their omission saves time.

Also, write pluses of stationing on margin. Use 4H pencil, large plain figures, but do not be fussy. Check back these figures.

3. (One man.) Plot profile points by referring to elevations marked in pencil. If reasonable care is taken in plotting this need not be checked.

4. Ink in ground line with light firm black ink line.

1. (c) **Cross-sections.** (See Sample Sheet.)

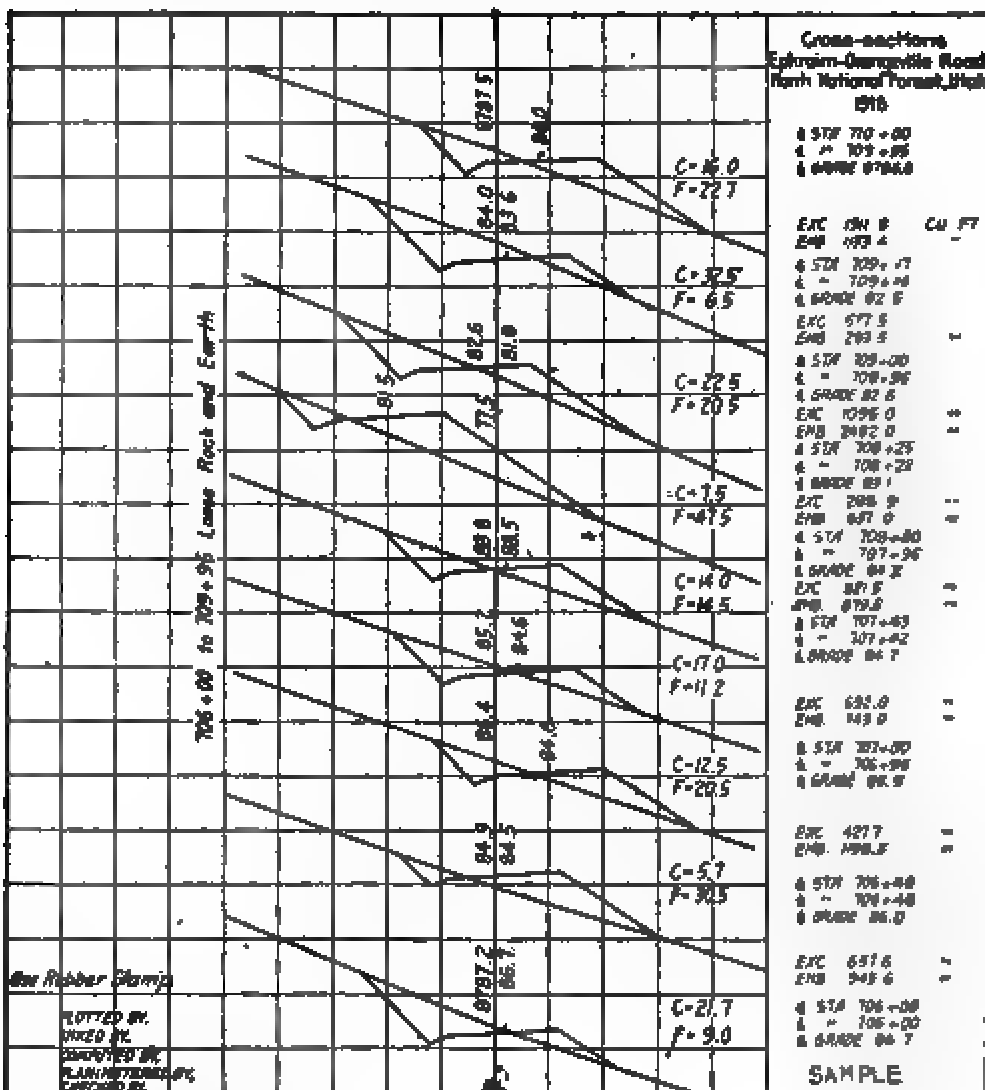


Fig. 136.

Plot on transparent cross-section paper cut in sheets 22″ × 36″ and ruled 1″ = 10 parts or 1″ = 5 parts heavy and 5 sub-divisions lighter.

Scale.—Use 1″ = 5′ except for exceptionally heavy work when 1″ = 10′ may be used.

Elevations.—Points must be plotted by their absolute elevation referred to the datum used for the Bench levels. The heavy lines outlining each square inch must be used as an even 5 ft. or 10 ft. of absolute elevation.

Order of Work. (Two men work together)

1. Mark base line verticals and use same vertical for all sections in each row. Generally two rows of sections can be placed on each sheet.

2. Plot ground line section points by dot surrounded by small circle and write in pencil, vertically, on the base line the elevation of the ground at the base line. Write on the right hand margin directly opposite and level with the intersection of the ground line and base line, the base line station and note it as B. L. Sta. 123 + 20.

3. Check all operations of plotting and recording by reading back from the actual plotted elevations. No corrections need be made for errors of 0.1 ft. Correct for any larger errors. It is extremely important that the cross-sections be accurately plotted and carefully checked as the design depends more on this phase of the work than on any other part.

Elevation and distances farther than 40 ft. from B. L. should be written in pencil, viz., $\frac{37.6}{45}$ $\frac{\text{Elev.}}{\text{Dist.}}$

1. (*d*) **Inking Cross-sections.** (One Man.)

Ink in checked pencil cross-sections.

Use firm, moderately heavy line (black ink) for the ground line.

Use large black ink heavy line letters and figures in marking Base Line elevations and station numbers.

NOTE.—*The Cross-sections must be inked before they are used in the design.*

DETAIL MANIPULATION

Grade Line Design.—2. (*a*) **Trial Grade Line.** (One Man, the Designer.)

On the base line profile draw on a trial grade in pencil (6H) using fairly long straight grades and cutting every bump and filling every hollow.

Remember that the object of the trial grade is to smooth out the profile on sidehill work by center line shift. It is fundamentally different from the final grade line which endeavors to follow the new center line profile as closely as possible.

2. (*b*) **Projecting Grade Contour on Map.** (Two Men.)

The grade contour should only be determined on sidehill work where the center line can be shifted to advantage. *Designers are cautioned not to use the grade contour method in flat or rolling country. Never destroy good alignment in easy country. It is preferable to use an undulating grade.*

Order of Work

1. On each cross-section determine the distance right or left of the base line where the trial grade line elevation for that particular section hits the ground line. Locate this by means of the absolute elevation of trial grade determined graphically from the grade profile.

Do not determine this point by the method of base line profile, cut or fill as this later method introduces more chance of error.

2. Note the location of these points by a light pencil vertical dash and write in pencil lightly the number of feet from the base line.

3. *Check this work.*

4. Plot these points on the detail map and mark them by a pin hole surrounded by a small red ink circle.

5. *Check this plotting.*

2. (*c*) **Projecting Final Center Line.** (One Man, Designer.)

1. Draw on map the proposed center line in pencil (6H) following as closely as possible the grade contour marked with the red circles, considering the limitations of alignment imposed by reasonable engineering considerations and the type of road desired. This work should be very carefully studied and is a slow operation. The curves should be drawn with the standard office curves or compass and their radii noted in pencil. The approximate locations of the P. C.'s and P. T.'s should be shown by short pencil lines perpendicular to the tangent. If possible short tangents should separate curves but this limitation must be used with judgment and is not intended to apply to extremely difficult or costly locations.

Make this projection with sufficient care so that the center line is practically settled on at this point of the design. *This is important.*

2. Mark the even stations on the new center line continuously by scaling. Use a standard scale on the tangents and the stepping method with dividers on curves. *Check this. Do not use the stepping method on tangents as it generally introduces a cumulative error.* Number every fifth station plainly in large figures.

3. Mark lightly in pencil the new center line stationing where each base line cross-section line previously drawn in red on the map intersects the new center line. *Check this.*

4. Mark lightly in pencil at each of these cross-sections the distance from the new center line to the base line and *check this.* You are now ready to transfer the location of the final center line to the cross-sections and plot the final center line profile.

3. (*a*) **New Center Line Profile.** (Two Men.)

Order of Work

1. Mark on cross-sections with a short vertical distinct pencil arrow the location of the adopted center line determined by the previously scaled and noted offset marked on the plan. *Check them.*

2. Directly under the noted base line station on the right hand margin of the cross-section sheet write in pencil the new center line station for each corresponding base line station as previously determined and shown on the map. *Check this.*

3. Mark in pencil the absolute elevation of the ground at the new center line. *Check this.*

4. Plot the true center line profile using the true center line

orizontal distances and stationing, the true center line ground evations as shown on the cross-sections and showing (as per imple profile) the equivalent B. L. stationing at each section. *Use the same manipulation methods as regards pencil and ink as escribed for base line profile.*

3. (*b*) **Balanced Section Profile.** (Made by Designer and one Helper.)

NOTE.—At this point eliminate from all further consideration the base line profile and trial grade. A great many men attempt to make the final grade similar to the trial grade which is absolutely the wrong principle except where a ruling grade governs.

Order of Work

1. Select the templet suitable to the cross-section under investigation.
2. Shift this templet up and down (with the center line always coinciding with the final center line location previously marked on the cross-section) till it reaches a point where by inspection you judge that the cut area will make the fill area as shown. Mark the center line elevation of the templet lightly in pencil with a short horizontal dash and write lightly the absolute elevation of this dash.
3. Plot the center line elevations of these balanced templets on the new center line profile for each section by a pencil dash using the absolute elevation previously determined. *Do not plot by plus or minus from the ground line as this introduces more chance of error.*
4. Check this plotting very carefully.
5. Ink the short dashes with red ink but do not connect these points.

NOTE.—This portion of the work is very important particularly on a fairly uniform profile. By the use of these balanced templet elevations the final grade can generally be balanced with less work, shorter hauls and from 10% to 30% less excavation than if a hit or miss method based on ground line is used. I cannot overemphasize the value of this part of the design. On an extremely rough profile requiring a succession of heavy cuts and fills it is not applicable nor advised.

3. (*c*) **Trial Final Grade Based on Balanced Templet Elevation.** (Designer must do this personally.)

Order of Work

1. Lay grade line on center line profile (in fine pencil 6H) following as nearly as possible the balanced elevations shown by the red dashes previously plotted on the profile.

Except where a ruling grade is encountered or where a tangent grade will hit the majority of the indicated balanced elevations, a rolling grade is to be preferred, this can be laid out most economically by a succession of vertical curves selected to fit the conditions.

These curves are drawn on the profile by the standard office rai curve templets and the radius noted. There is no necessit drawing the tangent grades to intersection as all the elevatio the vertical curves can be determined graphically. The ta rates of grade should be laid out to some even tenth and f between the ends of the vertical curves.

2. Determine elevations of grade line at each point wh section occurs and write this elevation in heavy pencil abov grade line. Do not record hundreds or thousands in these e tions. Determine these elevations graphically on vertical c and by figuring on tangent grades.

3. *Check these elevations.*

4. Transfer each elevation to the cross-sections by recording i pencil directly under the center line stationing on the right h margin of the sheet. *Check this transfer.*

3. (*d*) **Drawing in Templets.** (Designer should do this.)

Note.—This work should be done by the designer as consider judgment must be exercised in the selection and variation of t standard sections.

Order of Work

1. Draw in proper templet making its center line elevation ag with grade elevation previously recorded under the station num Use a 4H pencil with a fine point as many of these templets have to be changed before the design is accepted.

3. (*e*) **Planimetering Areas.**

Methods:

Various methods can be used depending on the kind of pl meter. So long as care is taken and a double run is made to ch the initial run any desired method will be satisfactory.

With a fixed arm planimeter reading directly to square inch double run divided by 8 is the usual practice for a 5′ scale.

With an adjustable arm planimeter it can be set to read sq feet directly on the second run or can be set to read cubic yards 100 ft. directly. The last method is a great time saver.

Order of Work

1. Check the correctness of templet plotting by compa templet elevation with grade elevation marked on the margin. *planimeter man is responsible for checking the templet plotting.*

2. Test planimeter before using and at frequent intervals see it is recording correctly.

3. Planimeter the areas checking by a double run.

4. Record the areas of cut and fill in pencil at the right of sections to nearest ft. as C = 21
F = 20.

COMPUTATION OF GRADING QUANTITIES

Order of Work

1. (Two men.) Transfer center line stationing and areas for each cross-section to the standard computation sheets. *Check this transfer.*

2. (One man.) Compute quantities. If areas are in sq. ft. compute quantities in cubic feet. *This is an order; no discretion is allowed.* The reason this is specified is because it has been determined from practice that it is quicker and more accurate. The more or less prevalent method of computing each quantity in yards will not be allowed. The use of cubic feet keeps all work in full units and eliminates 90% of the transfers, feet to yards. We have proved from checking that too many mistakes are made in the decimal point on detail yardage quantities.

3. *Check Detail Computations.*—This means check every phase of the computations, *distances* between sections, extensions, additions, etc.

3. (*f*) **Balancing Final Grade Line.** (Designer and one helper.) This portion of the design is very slow and requires more judgment than any other feature.

(*a*) It is desirable to balance in as short sections as possible as this results in cheaper excavation methods. A continuous balance means plow and road machine turnpiking which is very cheap.

Short balances mean scraper longitudinal haul and machine finish which is moderately cheap.

Long balances mean wagon haul which is expensive.

(*b*) It is desirable to balance with a downhill haul on noticeable grades.

(*c*) It is desirable to proportion the cut to fill so that dirt is not wasted.

This last is entirely a matter of judgment.

If the ground is bare and classed as common the following ratios will not be far out:

Volume of Exc. per Station	Ratio Cut to Fill
30 yd. to 50 yd.	1.30 to 1.25
60 yd. to 100 yd	1.25 to 1.18
Above 100 yd.	1.15 to 1.10

If the ground has a thick carpet of humus or a heavy stand of large trees the grading conditions can not be definitely determined until the clearing and grubbing is completed. In such a case the grade line should be noted as tentative and the resident engineer on construction will have to re-cross-section and re-design the grade after the mold and stumps are removed. The quantities in such a case can only be approximated and should be made on the safe side.

(*d*) In balancing quantities it is usually desirable to reduce the larger quantity.

(*e*) It is often cheaper and more desirable to waste at places and borrow at others. This should be borne in mind. The ratio of borrow excavation from pits to borrow fill is generally taken at 1.10.

(*f*) In considering rock cuts and fills use Trautwines' figures, 1 cu. yd. solid rock makes approximately 1.7 cu. yd. rock fill. Where the fill is a mixture of earth and rock 1 cu. yd. rock will make 1 cu. yd. of fill. The order of work and detail manipulation for the portions of the grade line that have to be changed to accomplish a balance are the same as for the original grade line.

3. (*g*) **Inking Final Grade.** After the grade line is balanced, ink it in with red ink on the profile so it can be easily traced.

4. **Estimate.**—(Designer.)

(1) *Drainage.*—From survey notes locate culverts on profile and draw them on the proper cross-section to determine length and invert elevations and outlet ditches if necessary. Do this work in pencil. Make notes clear and complete.

(2) *Bridges.*—Use standard designs up to 25′; above that have design made by Department Bridge designer.

(3) *Compilation.*—Compile data on forms provided, using center line station to locate all structures quantities, etc.

(4) Unit costs will be determined by the Office Engineer in charge of the Drafting Room and reviewed by the District Engineer.

(6) **Check all operations.**

5. (*a*) **Tracing Plans.**

Size of *Sheets:*

Outside 22″ × 36″
Border ½″ top, bottom and right.
2″ binding edge on left.

All work in black ink.
Make heavy and plain.
Lay out as per sample sheet.
Check all tracing.

5. (*b*) **Finishing Cross-section Sheets.** Do not ink in final grade, templets, or center line ground elevation till contract is let and cross-section blue prints are needed in the field. This delay is advisable as it is often necessary to revise even after the original design has been accepted.

EXPLANATION OF TABLE OF RELATIVE WEIGHTS OF OFFICE DESIGN

To obtain the equivalent mileage of completed office design multiply the actual mileage complete to date of each sub-division of the work by the precentage shown. Add all these products which will give you the total equivalent mileage of completed design.

Example.—Suppose at the time a report is due you have 10 miles of map completed, 20 miles of base line done and 5 miles of cross-sections plotted, checked and inked.

(*Continued page* 580.)

Illustrative Table for Determining the Percentage of Completion of Office Work for Weekly or Monthly Progress Reports

Relative Weights Office Design

Pioneer

	Per Cent. of Total Completed Plans
1. *Preliminary Work* (20% of Complete Plans):	
(a) Plotting map, checking and inking base line	5%
(b) Plotting, checking and inking base line profile	2%
(c) Plotting and checking cross-sections	10%
(d) Inking cross-sections	4%
2. *Final Center Line* (15% of Complete Plans):	
(a) Lay trial grade line on base line profile	1%
(b) Project trial grade line contour on map	4%
(c) Project final center line location on map	10%
3. *Final Grade Line* (50% of Complete Plans):	
(a) Make new center line profile on true center line elevations and distances, ink and check. (NOTE: At this point eliminate trial grade from all further consideration.)	7%
(b) Spot elevation of balanced cross-sections on new profile	5%
(c) Lay final grade line based on balanced section profile	5%
(d) Draw in templets	3%
(e) Planimeter and compute quantities and check	10%
(f) Balance quantities by grade line shift	19%
(g) Ink in final grade line	1%
4. *Compile Estimate* (5% of Complete Plans)	5%
5. *Trace Plans* (10% of Complete Plans)	10%
	100%

This work will be equivalent to the following mileage of complete office design:

Item		
1. (*a*) Map 10 miles × 5%	0.50	miles.
1. (*b*) Base line profile 20 miles × 2%	0.40	"
1. (*c*) Cross-sections plotted and checked 5 miles × 10%	0.50	"
1. (*d*) Cross- ection inked 5 miles × 4%	0.20	"
Equivalent miles total Completed Plans	1.60	"

Suppose the project is 20 miles long.
The per cent. completion office design is 1.6/20 = 8% complete.

BASIS OF TABLE OF RELATIVE WEIGHTS OFFICE DESIGN

General Speed.—Two miles per month per man of completed plans when men are experienced.

About 1¼ miles per month per man when force is not used to road design.

ASSUMED SPEED PER MAN PER DAY ON VARIOUS DIVISIONS OF WORK

1.	(*a*)	1.5 miles	Detail map.
*	(*b*)	3.0 "	Base line profile.
*	(*c*)	1.0 "	Cross-sections plotting and checking.
	(*d*)	1.5 "	Inking cross-sections.
2.	(*a*)	7.0 "	Trial grade
*	(*b*)	1.5 "	Grade contour.
	(*c*)	0.8 "	Center line projection.
*3.	(*a*)	1.0 "	Center line profile.
*	(*b*)	1.5 "	Balanced section profile.
	(*c*)	1.5 "	Final grade line.
	(*d*)	2.0 "	Templets
	(*e*)	0.8 "	Planimeter and quantities.
	(*f*)	0.4 "	Balance quantities.
	(*g*)	7.0 "	Ink final grade line.
4.		2.0 "	Compiling estimate.
5.		0.7 "	Tracing plans.

* Indicates work that can be done better by two men working together which will result in twice the speed shown.

SAMPLE ESTIMATE FORMS

SHEET NO.............

ESTIMATE SHEET (LETTER SIZE)

Road.................................Computed by..............................

Date.................................Checked by...............................

GENERAL SUMMARY			
ITEM	QUANTITY	UNIT PRICE	ESTIMATED COST
			$
Length.......miles Cost per mile..................	Total cost of Items +10% for Eng. Adm. & Cont. Cost to date for Surveys & Plans Appropriation		$ $

SHEET NO.............

ESTIMATE SHEET

Road.................................Computed by..............................

Date.................................Checked by...............................

SUMMARY CLEARING & GRUBBING						
STATION TO STATION	LENGTH	WIDTH	ACRES	CLASSIFICATION	PRICE PER ACRE	ESTIMATED COST
Totals						
	Average Unit Price per Acre					

SHEET NO.________

ESTIMATE SHEET

Road______________________________ Computed by________________
Date______________________________ Checked by________________

SUMMARY BORROW			
SOURCE OF SUPPLY STATION	WHERE USED STATION TO STATION	HAUL DISTANCE IN STAS.	QUANTITY CUBIC YARDS

SHEET NO.__________

ESTIMATE SHEET

Road______________________________ Computed by________________
Date______________________________ Checked by________________

SUMMARY OVERHAUL				
LOCATION OF CUT	LOCATION OF FILL STATION TO STATION	NUMBER CUBIC YDS.	LENGTH OF HAUL LIN.FT.	AMOUNT OF OVERHAUL IN STATION YARDS

SHEET NO.........

ESTIMATE SHEET

Road..Computed by........................
Date..Checked by..........................

SUMMARY CONCRETE STRUCTURES											
STATION	STRUCTURE	LENGTH	EXCAV.	BACK FILL	CLASS OF CONCRETE			METAL REINFORCEMENT			PAVING
					1ST CU. YDS.	2ND CU. YDS.	3RD CU. YDS.	MESH LBS.	BARS LBS.	DOWELS LBS.	

SHEET NO.........

ESTIMATE SHEET

Road..Computed by........................
Date..Checked by..........................

SUMMARY PIPE CULVERTS														
STATION	EXCAV.	BACK FILL	CONCRETE PIPE				CORRUGATED				VITRIFIED			
			LENGTH, LIN. FT.				LENGTH, LIN. FT.				LENGTH, LIN. FT.			
			18"	24"	30"	36"	15"	18"	24"	30"	12"	15"	18"	24"

SHEET NO.........

ESTIMATE SHEET

Road .... Computed by ....

Date .... Checked by ....

SUMMARY MASONRY STRUCTURES						
STRUCTURE	STATION TO STATION	LENGTH LIN. FT.	EXCAV. CU. YDS.	BACK FILL CU. YDS.	DRY RUBBLE CU. YDS.	MASONRY RUBBLE CU. YDS.

QUANTITY SHEET

No.......

Road .... Computed by .... Date ....

Section .... Checked by .... Date ....

CLASSIFICATION	STATION	DIST.	AREAS SQ. FT.		VOLUME — CUBIC FEET		COMMON
			CUT	FILL	CUT	FILL	EXCAV. CU. FT.

CHAPTER XIV

COST DATA AND ESTIMATES

AUTHOR'S NOTE.—In retaining the data in this chapter in its present form the author wishes to state that while the costs given are too low for the prevailing labor wage and cost of materials (1918) the analysis of cost can be used by applying the prevailing wage and material costs.

Undoubtedly the labor wage scale will remain permanently at a higher level than shown in the data given but it is not likely to remain at the present extreme height and until comparatively stable times prevail again, after the war, it would be useless to attempt to revise the unit cost data.

NEW methods of construction have so changed the cost of road improvements that engineers just going into this work, or those not familiar with present methods, are often handicapped in making estimates.

The cost data given in this chapter has been gathered chiefly since 1907 and covers most of the items necessary for estimating the cost of any ordinary road improvement. Such data must be used intelligently or it will be misleading. Local conditions should always govern in making estimates, and in presenting costs it is best to describe the conditions under which the work was performed, leaving their special application to the one using the data. An engineer's estimate should represent the probable average bid price. In the following examples of actual cost those have been selected that are considered to be average cases. Contractors who have an unusually good plant and a well-organized force can often do the work cheaper than is shown; on the other hand, those new to the work will spend more.

Where machinery is used it is more satisfactory to include the items of depreciation, repairs, and interest in a lump-sum item for the whole contract than to try to reduce it to a yardage basis. These charges will be considered under the heading of "Plant and Payroll."

BITUMINOUS AND WATERBOUND MACADAM CONSTRUCTION

Cost of Earth Excavation.—Table 56 shows the cost of earthwork on four roads in New York State, which represent easy, average, and difficult work. The cost per cubic yard includes excavation and placing in fill, shaping the sub-grade for the stone, and trimming the shoulders and ditches. For heavy fills with short hauls wheeled scrapers were used, but the largest part of the work was done by wagons.

Cost of Rock Excavation.—The writer has no reliable personal data on ledge rock excavation. Rockwork on roads is usually a small item; the cuts are small and consequently expensive. Perhaps there is no item more variable in cost than small rock cutting. It is therefore safer to take as a basis of estimate the bids of experienced road contractors. The reports of the Massachusetts Highway Commission and bids on New York State work show that prices for rock excavation range from $1.50 to $2 per cubic yard, for quantities up to 200 or 300 cu. yd., and $1.25 to $1.50 for larger quantities.

Cost of Unloading Broken Stone.—For making estimates of the quantity of stone required the following data on imported limestone used on Road 5021 will be useful. The approximate sizes and actual weights of stone on this work were as follows:

No. 1 Screenings, 5/8 inch screen.........	2550 lb. per loose cu. yd.
No. 1A Dustless screenings, 5/8 in. screen with dust jacket.................	2350 " " " " "
No. 2, 1¼ in. screen....................	2470 " " " " "
No. 3, 2½ " "	2350 " " " " "
No. 4, 3½ " "	2420 " " " " "

For purposes of estimating the cost of handling imported crushed limestone, the following weights for a cubic yard, based on railroad weights, will be used: No. 1, 2600 lb.; No. 1A, 2400 lb.; No. 2, 2500 lb.; No. 3, 2400 lb.; No. 4, 2400 lb.

Unloading Cars by Hand.—On Road 5021, with the author as engineer, a number of short time (10-hr.) estimates made the cost of unloading per ton $0.12 to $0.135; and the cost per cubic yard $0.14 to $0.16. This work was in 1910, and labor cost $0.175 per hour. The shoveling was done from a steel platform, where it was dumped from hopper-bottom cars. When shoveled from inside the cars the cost may run as high as $0.20 per cu. yd. The cost of shoveling is usually estimated at $0.15 per cu. yd.

The time of loading 1½ cu. yd. wagons by hand shoveling will range from 8 to 12 minutes.

Unloading Cars with Continuous Bucket Conveyor Elevator Plant.—Where there is a large quantity of stone to be unloaded and it is not possible to install an elevator plant on the existing track, it often pays to put in a switch. Six car switches can be usually built for about $300.00 Where there are competing railroads no charge is usually made.

The following data is from Road No. 5046, season of 1910, with labor at $0.175 per hour. The plant consisted of an ordinary continuous bucket conveyor operated by a 6 H.P. gasoline engine; the bin had a capacity of 100 tons.

The average fuel consumption was five gallons of gasoline per day. Cost of fuel and oil averaged $1.00 per day.

The average force at the elevator was one foreman and three helpers.

A total of 4670 tons, or 3890 cu. yd., was unloaded at $0.084 per ton, or $0.101 per cu. yd.

TABLE 56. EARTH EXCAVATION

Road No.	Length, Miles	Total Excavation Cu. Yds.	Wages per Hour		Cost per Cu. Yd.	Kind of Soil	Engineer
			Men	Teams			
1[1]	2.5	8,600	$0.175	$0.45	$0.452	Loam and gravel, easy work	E. E. Kidder
2	5.5	28,000	0.175	0.45	0.484	Largely clay, hard excavation	S. O. Steere
3	6.0	18,000	0.15	0.45	0.46	Gravel, sand, clay, loam, etc., average work	W. G. Harger
4[1]	4.0	10,000	0.175	0.40	0.65	25% of excavation, small boulders, unusually hard excavation	W. G. Harger

[1] The cost of trimming the shoulders on road No. 1 was $345.00 per mile; on road No. 4, $700.00 per mile.

The cost was divided as follows:

Setting up elevator at Scottsville	$ 60.00
" " " " Mumford	40.00
" " " " Wheatland	75.00
Labor of operation	194.00
Gasoline and oil	25.00
Total	$394.00

This method of unloading is not only cheaper than hand methods but also cheapens the cost of hauling, as no time is lost in loading the wagons. The time of loading a 1½ cu. yd. wagon from bins ranges from 45 to 55 seconds. There is also a saving in car demurrage if the bin holds two or three car-loads.

Elevator unloading saves about $0.04 per cu. yd. on team time and about $0.05 on the unloading, making a total saving per cubic yard of about $0.09. It usually costs about $150 to ship the plant and install it the first time, so elevator unloading is not adopted unless there are, at least, 2000 cu. yd. of stone handled.

Unloading Cars from Coal Trestle.—This data is taken from the Scottsville road repair work, Mr. Harold Spelman, Engineer, season of 1910; labor at $0.20 per hour; average force, two or three men. A total of 4400 tons was unloaded. The cost divided as follows:

Rent of trestle	$125.00
Labor	232.00
Total	$357.00
Cost per ton	0.081
" " cu. yd.	0.098

Unloading from Canal Boats.—The plant used consisted of a portable bin and a horse-operated derrick; Road 5014; Mr. James Anderson, contractor. The average amount of stone unloaded per day was 150 tons. The cost was $0.115 per ton, or $0.14 per cubic yard, divided as follows:

1 team and driver	$ 4.00	(10-hour day)
1 foreman	2.50	" " "
6 laborers, at $1.75 per day	10.50	" " "
Total	$17.00	" " "

Cost of Hauling Broken Stone.—Table 57 shows the cost of hauling stone on good roads as for repair work. The wagons were loaded from bins, so no time was lost in loading.

TABLE 57.—HAUL OF STONE ON GOOD ROADS FOR REPAIR WORK

Road No.	Engineer in Charge	Price per Hour of Teams	Length of Haul, Miles	Cost per Ton, Mile	Cost per Yard, Mile
1	Harold Spelman	$0.50	1.8	$0.20	$0.24
1	Harold Spelman	0.50	1.2	0.24	0.288
2	G. G. Miller	0.62	2.0	0.20	0.24
2	G. G. Miller	0.62	1.7	0.215	0.26
2	G. G. Miller	0.62	1.1	0.23	0.275
2	G. G. Miller	0.62	0.6	0.25	0.30
2	G. G. Miller	0.62	0.2	0.50	0.60
3	G. G. Miller	0.62	3.0	0.17	0.205
3	G. G. Miller	0.62	2.75	0.175	0.21
3	G. G. Miller	0.62	2.5	0.175	0.21
3	G. G. Miller	0.62	2.0	0.19	0.23
3	G. G. Miller	0.62	1.75	0.215	0.26
3	G. G. Miller	0.62	1.5	0.23	0.28

Road No. 1, 10-hour day.
Roads No. 2 and 3, 8 hours per day.

NOTE.—Cost per ton mile on Roads No. 2 and 3 equals the cost per yard mile, for teams at $0.50 per hour.

For hauling on bad roads for new construction I have the following personal data:

Clover Street Road, Section 1, season 1908; teams at $0.45 per hour; dump wagons loaded from bins; no time lost.

6000 cu. yd., 0.6 mile haul cost 26 ct. per ton, or 31 ct. per yard mile.

4500 cu. yd., 0.6 mile haul, cost 24 ct. per ton, or 29 ct. per cubic yard mile.

Scottsville-Mumford Road, season of 1911; teams, $0.45 per hour. 300 cu. yd., 1 mile haul (including a 5 per cent. sandy hill 1200 ft. long) cost $0.30 per yard mile.

500 cu. yd., 0.5-mile haul (level road in bad condition) cost $0.30 per yard mile.

Hauling Field Stone and Filler.—This material was hauled from fields and pits where it was loaded by hand, and considerable time thus lost.

On the Clover Street Road, Section 1, season of 1908, with the author as Engineer, and teams at $0.45 per hour, 10,000 cu. yd. of field stone were hauled an average of one mile for $0.36 per yard mile.

On the Scottsville-Mumford Road, season of 1911, with the author as Engineer, and teams at $0.45 per hour, 500 yd. of field stone were hauled 0.2 mile at $0.14 per cu. yd., or $0.70 per yard mile. On the same work 200 cu. yd. of filler were hauled 0.2 mile for $0.15 per cu. yd., or $0.75 per yard mile.

For all short hauls under ¼ mile the cost is high and practically the same on account of the larger percentage of time lost in loading.

Mechanical Hauling.—This method has not come sufficiently into general use to be considered in estimating, in the writer's opinion, unless it is difficult to get teams. It rarely pays to use traction engines for less than a three-mile haul, even on a hard road. In case they are used a light engine or road-roller and a train of ordinary dump wagons are more satisfactory than a heavy engine and large 5 or 7 cu. yd. cars. For maintenance and repair work, however, automobile trucks are the most economical. Under favorable circumstances mechanical hauling will cost about 12 to 15 cents per yard mile considering interest, depreciation, etc.

Cost of Loading Local Fence Stone into Wagons.—Road No. 5046, W. G. Harger, Engineer, season of 1911,
Labor $0.175 per hour.
2200 cu. yd., boulders loaded at a cost of $0.14 per cu. yd.

A gang of six men will take from 9 to 13 minutes in loading 1½ cu. yd., depending upon the size of the stone.

Road No. 495, E. E. Kidder, Engineer, season of 1911,
Labor $0.175 per hour.
1080 cu. yd., boulders loaded at a cost of $0.184 per cu. yd.

Road No. 492, E. E. Kidder, Engineer, season of 1911,
Labor $0.175 per hour, 300 cu. yd., loaded at $0.137 per cu. yd.

COST OF SPREADING STONE AND BINDER

Table 58, page 591, gives the cost of spreading broken stone on several New York State roads.

The ratio of the loose to the rolled depths varies with the size of the fragments and the depth of the course. Table 59, page 591, gives the averages of the results obtained from 1000 test holes made by the writer on three separate roads. The last column of the table also gives the weights of No. 3 and No. 4 stone required to make a cubic yard of rolled macadam. The amount of filler or binder per cubic yard of rolled macadam is given in Table 60, page 591.

The excessive amount of filler required for the 2-inch bituminous macadam, Table 60, was due to a layer of screenings placed under the No. 3 stone, all of which did not act as a filler. The small amount required for the 3-inch bituminous macadam was due to the fact that the bituminous binder partially filled the voids before the screenings were applied.

The ratio of loose to rolled depth for boulder sub-base is variable. If the size of boulders is practically the same as the depth of the course, that is, if there is only one layer of stone, the loose depth and the rolled depth will be the same. Where there are two or three layers of boulders the ratio is, approximately, 1:1.25, *i.e.*, a 12-inch, rolled depth would require 15-inch loose depth for boulders averaging 5 to 6 inches in diameter.

Cost of Loading Filler at Pit.—On the Clover Street Road, Section 1, during the season of 1908, with the author as engineer and labor at $0.15 per hour, 400 cu. yd. of sand filler were loaded at a cost of $0.12 per cu. yd. On the Scottsville-Mumford Road,

with labor $0.175 per hour, 200 cu. yd. were loaded at a cost of $0.13 per cu. yd.

TABLE 58.—SPREADING STONE

Reference No.	Engineer	Labor Wage	Depth of Loose Spread	Amount Spread	Cost per Ton	Cost per Cu. Yd.
1	Harold Spelman	$0.20	4 in.	7000 tons	$0.066	$0.08
2	W. G. Harger	0.175	5½ in.	6000 cu. yds.	0.05	0.06
2	W. G. Harger	0.175	4 in.	4500 " "	0.07	0.083
3	W. G. Harger	0.20	6 "	1000 " "	—	0.05
		Placing sub-base stone				
3	W. G. Harger	0.175	7 in.	100 " "	—	0.10
3	W. G. Harger	0.175	10 " gravel	200 " "	—	0.04
4	E. E. Kidder	0.175	6 "	267 " "	—	0.07
[1]5	E. E. Kidder	0.175	6 "	1082 " "	—	0.12

TABLE 59.—RATIO OF LOOSE TO ROLLED DEPTH

Size of Stone	Rolled Depth	Loose Depth	Ratio	Weight per Cubic Yard Rolled Measure[2]
No. 4	4 in.	5.2 in.	1.3	3120 lbs.
No. 4	3 "	3.8 "	1.27	3050 "
No. 3	3 "	3.9 "	1.3	3120 "
No. 3	2 "	2.4 "	1.2	2880 "

TABLE 60.—AMOUNT OF FILLER AND BINDER REQUIRED

Kind of Course	Kind of Filler	Amount of Filler per Cu. Yd. of Rolled Macadam	Weight of Screenings per Cu. Yd. of Rolled Macadam
Bottom stone	Sand	0.35 cu. yds.	—
Waterbound top[3]	No. 1	0.50 " "	1300 lbs.
3-in. Bit. mac. top[3]	Nos. 1A and 2	0.37 " "	900 "
2-in. Bit. mac. top[3]	No. 1A	0.60 " "	1440 "
Sub-base	Gravel	0.33 " "	—

Cost of Spreading Filler by Hand from Piles Spaced 20′ to 30′ Apart.—On the Clover Street Road, Section 1, during the season of 1908, with labor at $0.15 per hour, 400 cu. yd. of sand filler were spread at a cost of $0.10 per cu. yd. On the Scottsville-Mumford

Road, with labor at \$0.175 per hour, the cost of spreading 200 cu. yd. was \$0.20 per cu. yd. This includes some hand brooming, but most of the brooming was done by a broom attachment on the roller.

Cost of Spreading No. 1A and No. 2 Stone for Bituminous Macadam Top Courses and Brooming Same.—A layer of No. 1A, ½ inch deep, was spread over the bottom course. On this was spread 2½ inches of No. 3 stone. After rolling bitumen was poured over this course and a ¾-inch layer of No. 2 stone spread and rolled; the excess of No. 2 was broomed off and a ⅜-inch wearing coat of No. 1A placed.

The cost of spreading for a 2-in. top was as follows:

Cost of No. 1A and No. 2 per cu. yd.......	\$0.282
Cost per ton of No. 1A and No. 2..........	0.210

Eight hundred tons of this material were handled with labor costing \$0.175 per hour.

For a 3-in. top course the procedure was the same, omitting the layer of No. 1A under the No. 3 stone. The cost of handling 400 tons for the 3-in. course was as follows:

Cost per cu. yd. of No. 1A and No. 2........	\$0.31
Cost per ton of No. 1A and No. 2	0.26

Cost of Spreading Screenings with Cross Dump Wagons.—Wet dust screenings for waterbound macadam can not be successfully spread in this manner. For spreading dry dust screenings, No. 2 stone or dustless screenings for bituminous macadam, this method has proved the cheapest and most satisfactory. On Road 5046, season of 1910, a number of short-time estimates made the cost of spreading by this method about \$0.06 per cu. yd. The cost of brooming is slightly increased over that required by the hand-spreading method, but not enough to counteract the advantage in the use of the wagon spreading. On the Clover Street Road, season of 1908, 1000 cu. yd. of screenings were thus spread for about \$0.07 per cu. yd.

COST OF ROLLING

In the following costs lubricating oil is not included, as no reliable data were obtained as to the quantity used. Gillette's "Handbook of Cost Data" gives this item as \$0.30 per day; using this amount would increase the costs given below from 0.2 to 0.3 of a cent per cu. yd. The amount of coal used was variously estimated at from 450 to 500 lb. per day. As before mentioned, items of depreciation, repairs of plant and equipment, and interest are not included in the cost per cubic yard of stone consolidated.

On Road 5025, under Mr. E. E. Kidder, Engineer, during the season of 1910, the cost of rolling 3400 cu. yd. of bottom stone and 1700 cu. yd. of top stone, loose measure, was as follows:

Rollerman, 4 months, at \$90	\$360.00
Coal, ¼ ton per day, at \$2.70 per ton, 80 days	55.00
	\$415.00

The time and cost were divided as follows:

1/6 on sub-grade	$ 69.00
1/3 on bottom stone 4″ deep	138.00
1/2 on bituminous top stone, 2″ deep	208.00

There was no cost for water. The roller worked 80 days in 4 months. The cost of rolling per cubic yard of loose material was: bottom stone, $0.04, and top (bituminous macadam) $0.12.

On Road 492, Mr. E. E. Kidder, Engineer, season of 1910, the cost of rolling 3700 cu. yd. of 4-in. bottom course was $0.03 per cu. yd., and for 3200 cu. yd. of waterbound top stone $0.05 per cu. yd. Both quantities refer to loose measure. The roller worked 74 days in three months. The puddling was done by a pipe line and hose and brooms attached to the roller. The rollerman's wages were $90.00 per month and coal $2.75 per ton.

On Road 5021 the cost of rolling a 3-in. bituminous top course per cubic yard of loose material was $0.09; for a 2-in. top $0.11.

On Road 5046 a roller working 111 days consolidated 1850 cu. yd. of field stone sub-base, 4300 cu. yd. of bottom stone, and 2150 cu. yd. of top stone, loose measure. The depth of the sub-base was 6 in. (rolled measure), the bottom course 4 in., and the top course 2½ in., bituminous macadam. The rollerman's wages were $90 per month and coal cost $2.75 per ton for ¼ ton per day. There was no cost for water. The costs were divided as follows: sub-base, $0.035; bottom stone, $0.045; top stone, $0.105 per cu. yd., loose measure.

COST OF CRUSHING STONE

As a basis for all cost estimates for crushing, it is necessary to know something of the percentage of the different sizes of the crusher output. Table 61, page 594, gives the results of tests made by Mr. Archer White during the season of 1910 on ordinary limestone and sandstone boulders composing the average field stone. The crusher used was the largest Acme portable crusher. The tailings were recrushed and the stone divided into four grades: No. 1, ¾-in. screen; No. 2, 1½-in.; No. 3, 2½-in., and No. 4, 3½-in. From these data it may be seen that 1 cu. yd. of field stone makes 1 cu. yd. of crushed stone, and that it takes approximately 1.8 cu. yd. of field stone to make 1 cu. yd. rolled measure of sizes Nos. 3 and 4. The crusher toggle was set to produce both top and bottom stone sizes.

The cost of labor was $0.20 per hour. The engineman of the crusher plant received $0.25 per hour and the foreman $0.30 per hour. The field stone was loaded from a pile near the crusher into small dump cars running on a movable track. The loaded cars were drawn to the crusher by a small hoisting engine. The cost of bringing the field stone to the crusher pile is not included. The force loading consisted of one foreman, eleven laborers, and one engineman. The force crushing consisted of one foreman, four laborers, and one engineman. In eight days 1500 cu. yd.

TABLE 61.—SIZES AND PROPORTIONS OF CRUSHER RUN

Reference No.	Cu. Yds. Field Stone Delivered to Crusher	Cu. Yds. Crushed Stone Produced	Number 1		Number 2		Number 3		Number 4		Kind of Material
			Cu. Yds. Produced	% of Total Output	Cu. Yds. Produced	% of Total Output	Cu. Yds. Produced	% of Total Output	Cu. Yds. Produced	% of Total Output	
1	195	190	36	19	18	9	64	34	72	38	Sandstone and limestone
2	187	182	32	17½	10	5½	70	38½	70	38½	Limestone
3	196	202	36	18	14	7	76	38	76	37	Limestone and sandstone
4	190	216	40	18	18	8	79	37	79	37	Sandstone
5	173	172	32	19	28	16	62	36	50	29	Poor sandstone
6	189	184	36	19½	16	9	*	—	132	71½	Limestone
7	165	170	32	19	22	13	*	—	116	68	"
8	—	—	30	16	24	13	*	—	60	63	Soft sandstone

* No. 3 and No. 4 size mixed and placed on grade.

were crushed. The cost of the entire output per cubic yard of loose measure was divided as follows:

Loading stone for crusher	$0.133
Hauling to crusher	0.013
Feeding to crusher	0.061
Engineer to crusher	0.013
Fuel and oil	0.030
Loading crushed stone from bins	0.010
Total	$0.260

Crushing Granite Hardheads and Sandstone.—The following data is from the records of the Clover Street Road, Section 1, season of 1908. Labor cost $0.15 per hour and the engineman received $3 per day. The crusher used was a 10″ × 20″ Climax. A total of 5000 cu. yd. of granite were crushed at a cost per cubic yard, loose measure, of $0.19; 7000 cu. yd. of sandstone boulders were crushed at a cost of $0.103 per cu. yd., loose measure. These figures are for the total output of the crusher and include the cost of feeding to the crusher, the pay of the engineman, coal, oil, but not the delivery to the crusher. On the Scottsville-Mumford Road under similar conditions the cost varied from $0.13 for granite and sandstone to $0.19 for granite hardheads per cubic yard of loose measure.

Crusher force on the Clover Street and Scottsville-Mumford roads as follows:

1 foreman	$4.00
5 men feeding crusher	2.00 each
1 man tending screen	2.00
1 engineer	3.00
Fuel and oil	4.00

Where bottom stone alone is being crushed from local material the crusher is set to produce a larger amount of No. 4 stone, and the proportion of the screenings to the No. 3 and No. 4 size is different than given in Table 61.

In the following data from Road 5046, Scottsville-Mumford, mentioned above, the No. 3 and No. 4 and tailings were used as the bottom course stone, the tailings being broken into proper sizes after the stone was spread by knapping hammers. The cost of knapping will vary from $0.01 to $0.03 per cu. yd. of loose bottom stone, depending on the number of tailings produced. When the crusher is set correctly to deliver a good grade of stone for bottom course, this charge should not amount to over $0.01 per cu. yd. of total output and is properly chargeable against crushing, which increases the crushing costs given above from $0.13 to $0.14 and from $0.19 to $0.20.

The sizes of screens were 5/8″, 1 1/4″, 2 1/2″ and 3 1/2″.

Crusher Set-up, No. 1.—60% granite, 30% sandstone, 10% soft rock.

Total screenings, No. 1	240 cu. yd.
" No. 2	no record
" No. 3, 4, and tailings	1500 cu. yd.

Crusher Set-up, No. 2.—50% granite, 40% sandstone, 10% soft rock.

Total screenings	350 cu. yd.
" No. 2	no record
" No. 3, 4, and tailings	2600 cu. yd.

For this same road the amount of field stone required per loose yard of bottom stone is shown by the following figures. Approximately 1.5 yard loads were drawn to and from crusher.

Date	Number Loads of Field Stone Crushed	Number Loads of No. 3 and No. 4 and Tailings Drawn from the Crusher
1911		
April 24	114	93
" 25	86	70
" 26	87	69
May 5	104	84
" 6	101	82
" 8	106	85
" 9	99	78
" 10	86	72
" 11	107	95
" 12	110	80
" 13	102	83
Totals	1102 loads 1653 cu.yds.	891 loads 1336 cu. yds.

On this work 1.24 cu. yd. field stone produced 1 cu. yd. loose measure bottom stone, and 1.61 cu. yd. field stone produced 1 cu. yd. bottom stone rolled measure.

Table 61, page 594, gives 1.8 cu. yd. field stone to 1 cu. yd. rolled macadam, but this apparent difference is explained by the fact that the tailings were recrushed and the crusher set closer to produce top as well as bottom stone, consequently the per cent. of No. 1 and No. 2 is higher than for the data just given.

Data obtained by Mr. Frank Bristow, First Assistant Engineer,

New York State Department of Highways, indicates that 1 cu. yd. of field stone produces 1.1 cu. yd. crushed stone when separated by screens of ½", 1¼" 2½", and 3½"; this is slightly more than the writer's experience has indicated.

When local stone is crushed for bottom only, the screenings are used as filler for that course, and in a case of this kind it is necessary to know how much additional filler must be estimated. Take the case of the Scottsville-Mumford Road (crusher set-up No. 2) given above. Twenty-six hundred cubic yards loose measure will consolidate under the roller to approximately 2000 cu. yd. of rolled bottom stone. This will require $2000 \times 0.35 = 700$ cu. yd. filler. The amount of screenings produced in crushing 2600 cu. yd. of bottom was 350 cu. yd., showing that for cases similar to the one given, half of the total filler required must be obtained from other sources.

Cost of Sledging Boulders.—A certain percentage of the fence stone must be broken to reduce them to a proper size for crushing. This is done by blasting or sledging; where the boulders need to be broken only two or three times to reduce it to a usable size, sledging is the cheaper method. The cost of both of these methods is so variable that any cases cited would not be of much value. As given on page 636, under Standard Estimates, the author allows arbitrarily $0.40 per cu. yd. for all boulders actually sledged or blasted, and in making estimates the per cent. to be treated in this manner is approximated roughly.

As a matter of interest Gillette, in his cost data on rockwork, gives the cost of sledging small sandstone boulders as approximately 0.05 per cu. yd., and the cost of mud capping at about 0.35 per cu. yd.

COST OF CRUSHING (continued)

The following data is taken from the Report of the Massachusetts Highway Commission and refers to work done in Newton, Mass. The crushed stone was divided into the following sizes:

Tailings	205 cu. yd.	17.5%
2½" stone	692 " "	57.0%
Screenings and 1"	300 " "	25.5%
Totals	1197	100.0%

The material was cobblestones and labor probably cost $0.20 per hour, teams, $0.45. The cost per cubic yard at the crusher was $0.445, or $0.33 per ton.

The cost per cubic yard was divided as follows:

Teaming to crusher	$0.314	70.6%
Feeding to crusher	0.033	7.4%
Engineer of crusher	0.029	6.5%
Repairs, coal, oil, etc	0.045	10.1%
Watchman	0.024	5.4%
Total	$0.445	100.0%

Material. Conglomerate.

Amount broken		1288 cu. yd.
Amount broken per hour		8.9 " "
Divided as follows:		Weight per Cu. Yd. Loose
Tailings, 378 cu. yd.	29.3%	2549 lb.
2½" stone, 668 cu. yd.	51.9%	2368 "
Screenings and 1", 242 cu. yd.	18.8%	2727 "

Cost per cu. yd. in bins at crusher $1.112

Cost per ton in bins at crusher 0.885

Divided as follows:	Cost	Per Cent.
Powder and repairs	$0.018	1.6
Labor drilling	0.249	22.3
Sharpening drills and tools	0.023	2.1
Breaking stone for crusher	0.420	37.8
Loading stone for crusher	0.127	11.4
Hauling stone for crusher	0.062	5.6
Feeding crusher	0.053	4.7
Engineer for crusher	0.038	3.5
Coal, oil, and waste	0.050	4.5
Moving and setting crusher	0.023	2.1
Watchman	0.049	4.4
Total	$1.112	100.0

Material. Greenish trap.

Amount broken		3155 cu. yd.
Amount broken per hour		7.7 " "
Divided as follows:		Weight per Cu. Yd. Loose
Tailings, 1004 cu. yd.	31.8%	2457 lb.
2½" stone, 1618 cu. yd.	51.3%	2383 "
1" stone, 323 cu. yd.	10.2%	2277 "
Screenings, 210 cu. yd.	6.7%	2585 "

Cost per cu. yd. in bins at crusher $0.898

Cost per ton in bins at crusher 0.745

Divided as follows:	Cost	Per Cent.
Labor, steam, drilling	$0.092	10.3
Coal, oil, waste, powder, etc.	0.084	9.4
Sharpening drills and tools	0.069	7.7
Breaking stone for crusher	0.279	31.0
Loading stone for crusher	0.098	11.0
Hauling stone for crusher	0.072	8.0
Feeding crusher	0.053	5.9
Engineer of crusher	0.031	3.4
Coal, oil, waste, and repairs of crusher	0.079	8.8
Other repairs	0.041	4.5
Total	$0.898	100.0

W. E. McClintock, Engineer, Chelsea, Mass., season 1887:

Labor	\$0.20 per hour
Teams	0.45 " "

Material. Trap rock.

Amount broken	1718 tons

Stone delivered at crusher by sub-contractor for \$0.75 per ton.

Cost.	Tools	\$0.013
	Oil, waste, etc.	0.016
	Fuel	0.050
	Stone at crusher	0.750
	Crushing (labor)	0.194
	Total per ton	\$1.023

Dustless Screenings.—The construction of bituminous macadams requires a dustless screening product referred to in the beginning of the chapter as No. 1A; it is obtained by rescreening the ordinary screenings (3/4" product) to remove the dust; the percentage of dust in the ordinary screenings will vary according to the stone crushed and the setting of the crusher jaws. The author has no reliable data for small crushing plants, but through the courtesy of the Buffalo Cement Company the following data is given for their output of limestone screenings at Buffalo, N. Y.

Size of screen opening for ordinary screenings	3/4"
Size of dust screen openings	1/8"

Cu. yd. of dust for 1 cu. yd. ordinary screenings	0.35
" " " dustless screening 1 cu. yd. ordinary screening	0.65

The same data from the Leroy plant of the General Crushed Stone Company gives:

Size of screen openings for ordinary screenings	5/8" to 1 1/16"
" " dust screen openings	1/4" " 5/16"
Cu. yd. of dust per cu. yd. ordinary screenings	33%
" " " dustless screenings per cu. yd. ordinary screenings	67%

Percentage of screenings to total output for Leroy limestone approximates 15%.

The above furnished to the writer through the courtesy of the General Crushed Stone Company, of Easton, Pa.

COST OF STONE FILL BOTTOM COURSE

The following data is taken from Road 5021, season of 1910; labor cost \$0.175 per hour, teams \$0.40 per hour.

The amount placed was 10,000 cu. yd. rolled measure. The average rolled depth was 1.1 ft. The surface was carefully brought to line and grade, allowing a variation of 1 in. either above or below, which inequality was taken out with the top stone. A 3 in. bituminous top course was placed directly on this fill. The

top layer of bottom stone was sledged to reduce all stones to 8 in. or under. Flint stone was used to fill the top 6 in. and to surface the rough fill. The bottom course was of fence stone, hauled, on an average, about one-half mile. I estimate that one cubic yard rolled measure requires 1.25 cu. yd. loose. The cost of the bottom course per cubic yards rolled measure was $1.03, divided as follows:

Loading 1.25 cu. yd	$0.19
Hauling 1.25 " " ½ mile	0.20
Placing 1.25 " " and rolling	0.24
Sledging	0.15
Flint	0.10
Cost of fence stone	0.15
Total, per cu. yd	$1.03

Cost of Sub-base Bottom Course.—Road 495, Parma Corners-Spencerport. E. E. Kidder, Engineer. 1082 cu. yd. placed, average depth 6″. Not much sledging required.

Cost of stone, 1 cu. yd	$0.10
Loading, per 1 " "	0.184
Hauling 1 mile	0.30
Laying, sledging and spreading filler	0.136
Rolling	0.02
Superintendence	0.02
Cost of filler in pit nothing (gravel used)	0.00
Loading ⅓ cu. yd	0.04
Hauling ⅓ cu. yd. 1 mile	0.10
Total	0.90

COST OF APPLYING BITUMINOUS BINDER

The following data is taken from Road 5021, season of 1910. Bituminous macadam, penetration method:

Labor.

Kettleman	$0.20	per hour
Spreaders	0.20	" "
Plain labor	0.175	" "
Teams	0.45	" "

Apparatus.

4 bbl. kettle (coal burner)............. Bitumen heated
2 bbl. " (wood burner)............ to 400° F.
12 ton Kelly roller..................
Spreading pots having a vertical slot ⅛″ wide.

Organization.

Rollerman acting as foreman
1 Spreader
1 Kettleman
3 Laborers

Average speed 350 ft. of 16 ft. road, per day.

Quantities.

16,850 gal. laid in one coat covered 13,330 sq. yd., or 1.26 gal. per sq. yd.

Cost per gal.	Unloading and hauling ½ mile	$0.0015
	Heating	0.0032
	Spreading	0.0032
	Rolling and supervision	0.0051
	Total	$0.0130
Bituminous material f.o.b. Caledonia		0.0950
	Total per gal	$0.1080

Second quantity.

Forty-two thousand gallons covered 24,000 sq. yd. in one coat, an average of 1.75 gal. per sq. yd.

Cost per gal.	Unloading and hauling 1¾ miles	$0.0032
	Heating	0.0040
	Spreading	0.0039
	Rolling and supervision	0.0042
	Total	$0.0153
Bituminous material f.o.b. Caledonia		0.0950
	Total per gal	$0.1103

Cost of Applying Bituminous Binder. Road 5046, *Penetration Method.*

18,890 gal. spread on 12,378 sq. yd. in one coat, of 1.52 gal. per sq. yd.

Apparatus.

5 2 bbl. kettles (wood burners) Fuel. Used bbl. staves and some extra wood.

1 10-ton Buffalo Pitts Roller.

Spreading hods.

Organization.

	Per Hour
1 Foreman	$0.30
2 Pourers, each	0.25
5 Kettlemen, each	0.20
2 Spreaders of No. 2, each	0.20
4 Helpers, each	0.175

Labor of Placing. Cost per gallon.

Fuel	$0.001
Kettlemen	0.005
Pouring	0.003
Helpers	0.007
Supervision	0.002
Total	$0.018
Material f.o.b. Scottsville	0.093
Total per gal	$0.111

Kentucky Rock Asphalt.—I have the following data from the Clarence Center Road, Mr. John D. Rust, Engineer, collected during the season of 1910. In this work an 8-ton tandem roller was found to do better than a 6-ton tandem. The cost of handling, spreading, and rolling this material, from data of five days selected, varied from $0.033 to $0.036 per sq. yd.; the average being $0.034. The following may be taken as a typical analysis of this cost:

Abbreviations. L. Laborers.
F. Foreman.
T. Teams.
E. Roller engineer.

Asphalt $10.25 per ton f.o.b. unloading point.
Run of July 20, 1909.
69.22 tons hauled and placed.
1730 sq. yd. covered.
80 lb. asphalt per sq. yd.

5 L. at cars, 10 hours, at $1.50 each	$ 7.50
½ F. at cars at $2.25 per day	$ 1.12
5 T. haul 2 miles at $4.00 per team	20.00
5 L. on wheelbarrows, 11 hours, each $0.15 per hour	8.25
1 T. at shredding machine	4.40
3 L. on rakes, 11 hours at $0.15 per hour	4.95
3 L. shoveling, 11 hours, at $0.15 per hour	4.95
1 F. at shredder, 11 hours at $0.225 per hour	2.48
1 E. on roller, 11 hours at $0.30 per hour	3.30
Total	$56.95
Cost per square yard,	$ 0.033.

PUDDLING WATERBOUND ROADS

There are two methods of puddling:
First, by Pipe Line and Hose.
Second, by Sprinkling Carts.

In the first method a 1½-in. or 2-in. pipe is laid along the road with taps every 200 to 300 feet. The road is wet down by a hose fastened to these taps and sprayed on by a nozzle, or the hose is fastened to a sprinkling attachment on the roller, which throws

the water directly onto the wheels; this method is cheaper and more satisfactory than using sprinkling carts, but to work well a pressure of 125 lb. should be maintained at the pump, which requires a better pumping apparatus than contractors usually have. A very satisfactory plant, used near Rochester, N. Y., consisted of a Gould Triplex Pump, operated by a 6-H.P. gasoline engine; the relief valve at the pump was set at 120 lb.

The cost of such puddling on Road 492 for 3000 cu. yd. of top course was \$0.05 per cu. yd.; on Road 294 for 4000 cu. yd. of top course it was \$0.06. This cost includes pumping, helper tending hose, and rollerman. Brooms on the roller were used which materially reduced the cost of brooming the screenings. No charge for water, no allowance made for laying the pipe line; this last charge is included in the lump-sum item of installing plant for a waterbound road, page 631.

Gillette, in his handbook, gives sprinkling by carts approximately \$0.10 per cu. yd. of top course, which includes sprinkling the sub-grade as well as puddling the top course. As the sub-grade is rarely sprinkled, his data reduced to the conditions cited on roads 492 and 294 would give approximately \$0.06 per cu. yd. of top course. To this is added the cost of rolling, or about \$0.04, which makes the cost of puddling by this method about \$0.10 to \$0.12, or about twice the amount of the first method.

Mr. E. A. Bonney, on the Hamburg-Buffalo road, from a metered supply of water, states the amount required to first puddle a 3-in. top course varies from 50 gal. to 55 gal. per cu. yd. of top course, and the amount needed for the second puddle will be considerably less.

Mr. H. P. Gillette states, in a monograph on the Economics of Road Construction, that 30 gal. of water per cu. yd. will puddle a road. Mr. E. E. Kidder states that approximately 80 gal. are required per cu. yd. of top course for two puddles. The author's experience agrees with the larger quantities.

McClintock Cube Pavement.—The general costs of this experimental pavement were given in chapter VI. We here give the detailed cost of the vitrified clay cubes and clay-ash cubes only, as the concrete cubes have not worn satisfactorily.

Vitrified Shale Cubes.—During 1909, 74,000 2½-in. vitrified shale cubes manufactured at Reynoldsville, Pa., were laid at a cost as follows:

Teams at \$0.50 per hour

74,000 cubes f.o.b. Reynoldsville	\$231.25
Freight	68.41
Carting	67.00
Laying	20.00
Total	\$386.66

NOTE.—331 sq. yd. were covered at a cost of \$1.17 per sq. yd.

Clay and Ash Cubes.—In 1910, cubes made of a local clay mixed with ashes and burned were tried in the effort to get a cheap,

tough clay product. As far as known, this is the first time bricks made in this way have been used on roadwork.

The ash-clay process has been worked out and patented by Karl Langenbeck, of Boston, Mass. Many local clays used for ordinary brick or farm tile will not stand up under vitrification without the addition of expensive, imported refractory clays; but the substitution of coal ashes for the more expensive clays has a similar effect and the cost is materially reduced. Some of the local clay was sent to Mr. Langenbeck, who turned out a few cubes that compare favorably in toughness with the best paving bricks on the market.

The Standard Sewer Pipe Company, of Rochester, N. Y., undertook to furnish 400,000 2-in. cubes of this description for Mr. McClintock. It was necessary for them to experiment to determine a practical method of molding, the correct temperature to use, and the best proportion of ashes, which naturally raised the price above ordinary practice. In molding they used a modification of the ordinary pipe-molding machine, which produced a hollow square of cubes, at the rate of 30,000 cubes per hour. The scoring knives were so set that the cubes were nearly cut apart, leaving just enough uncut clay to hold them together during the burning, after which a light blow separated them cleanly. The toughness of the resulting cubes can probably be increased by further experiment; but the product was good, although not up to the standard of the sample cubes made by Mr. Langenbeck.

The cost of the ash-clay cubes was as follows:

400,000 cubes f.o.b. Rochester, N. Y.	$1200.00	$0.711 per sq. yd.
Carting, six miles	247.75	0.147 " " "
Filler	27.00	0.016 " " "
Labor of laying	191.77	0.113 " " "
Roller	12.94	0.008 " " "
Total	$1679.46	$0.995 " " "

NOTE.—1688 sq. yd. covered
Labor, $0.22 an hour
Teams, $0.50 an hour } for laying and carting.

Mr. McClintock has stated, in discussing the cost, that in large quantities he believes the cubes can be delivered f.o.b. at the plant for $1.50 per 1000, which would reduce the cost as shown above to about $0.60 per sq. yd., and that the high cost of laying was due to the irregular shape of the first batch, due to not scoring the cubes deely enough.

Amiesite Cost Data.—Road 1319, Honeoye Village, Season of 1915. H. W. Baker, Eng. in charge. 4700 sq. yd. laid 16′ wide 2¾″ deep. Laid in two courses. Bottom course 2¼″ thick coarse material; surface ½″ thick fine material.

Material

588 tons @ $4.00 per ton f.o.b. plant	$2352.00
588 tons freight $0.54 per ton	341.04
Total cost materials	$2693.04

Labor	
Force at cars unloading	
6 Laborers @ $2.00 per day	$12.00
1 Foreman @ $2.50 per day	2.50
1 Fireman @ $3.00 per day	3.00
1 Night Fireman @ $2.50 per day	2.50
	$20.00
Equipment at Cars	
1 boiler and pipe line per day	8.00
½ ton coal and oil	2.50
Total daily cost of unloading	$30.50
Hauling ¾ mile	
4 teams @ $5.00 per day	$20.00
Spreading and Compacting	
1 Asphalt raker	3.00
4 Laborers @ $2.00 per day	8.00
1 Rollerman	3.00
per day	$14.00
Equipment	
1 roller (10 ton tandem)	10.00
Coal, oil, etc.	0.80
Daily cost spreading and compacting	$24.80
Summary Daily Force Account	
Unloading	30.50
Hauling	20.00
Spreading and compacting	24.80
	$75.30
Number of days worked, 15	
Total labor 15 days	$1129.50
" materials cost	2693.04
Total cost	$3822.54
Cost per sq. yd.	0.81
Bid price sq. yd.	0.85

Conditions

This work was done under bad weather conditions the night temperature being below freezing and only two days with an air temperature above 55° F.

It was necessary to keep a night fireman at the cars to keep up steam and to move the steam pipes to different parts of the cars to insure the amiesite being in a condition to loosen and shovel in the morning. The material was loosened by bars and sledges to the bottom of the cars steamed 10 to 30 minutes and then shoveled into dump wagons, covered with canvas and hauled to the street.

Under favorable weather conditions the cost of unloading from the cars would probably be reduced 40%.

Table of Amounts of Amiesite required for different thicknesses and materials, page 606.

Amiesite. TABLE OF DEPTHS AND WEIGHTS — (*Weights Given are per Square Yard*)

	Amiesite Loose	Weight Pounds	Amiesite Sq. Yds. Per Ton	Filler Loose	Weight Pounds	Filler Sq. Yds. per Ton	Total Depth Loose	Total Weight Pounds	Ultimate Compression	Square Yds. Per Ton
LIMESTONE	$2\frac{1}{4}''$	153	13	1″	$67\frac{3}{4}$	29.5	$3\frac{1}{4}''$	$220\frac{3}{4}$	2″	9.06
	$2\frac{5}{8}''$	$178\frac{1}{2}$	11.3	1″	$67\frac{3}{4}$	29.5	$3\frac{5}{8}''$	$246\frac{1}{4}$	$2\frac{1}{4}''$	8.12
	3″	204	9.8	1″	$67\frac{3}{4}$	29.5	4″	$271\frac{3}{4}$	$2\frac{1}{2}''$	7.36
	$3\frac{3}{8}''$	$229\frac{1}{2}$	8.7	1″	$67\frac{3}{4}$	29.5	$4\frac{3}{8}''$	$297\frac{1}{4}$	$2\frac{3}{4}''$	6.73
	$3\frac{3}{4}''$	255	7.8	1″	$67\frac{3}{4}$	29.5	$4\frac{3}{4}''$	$322\frac{3}{4}$	3″	6.2
TRAP ROCK	$2\frac{1}{4}''$	$168\frac{3}{4}$	11.8	1″	75	26.6	$3\frac{1}{4}''$	$243\frac{3}{4}$	2″	8.2
	$2\frac{5}{8}''$	$196\frac{7}{8}$	10.2	1″	75	26.6	$3\frac{5}{8}''$	$271\frac{7}{8}$	$2\frac{1}{4}''$	7.36
	3″	225	8.9	1″	75	26.6	4″	300	$2\frac{1}{2}''$	6.66
	$3\frac{3}{8}''$	$253\frac{1}{8}$	7.9	1″	75	26.6	$4\frac{3}{8}''$	$328\frac{1}{8}$	$2\frac{3}{4}''$	6.1
	$3\frac{3}{4}''$	$281\frac{1}{4}$	7.1	1″	75	26.6	$4\frac{3}{4}''$	$356\frac{1}{4}$	3″	5.6
SANDSTONE	$2\frac{1}{4}''$	$164\frac{1}{4}$	12.2	1″	73	27.4	$3\frac{1}{4}''$	$237\frac{1}{4}$	2″	8.43
	$2\frac{5}{8}''$	$191\frac{5}{8}$	10.4	1″	73	27.4	$3\frac{5}{8}''$	$264\frac{5}{8}$	$2\frac{1}{4}''$	7.56
	3″	219	9.1	1″	73	27.4	4″	292	$2\frac{1}{2}''$	6.85
	$3\frac{3}{8}''$	$246\frac{3}{8}$	8.1	1″	73	27.4	$4\frac{3}{8}''$	$319\frac{3}{8}$	$2\frac{3}{4}''$	6.26
	$3\frac{3}{4}''$	$273\frac{3}{4}$	7.3	1″	73	27.4	$4\frac{3}{4}''$	$346\frac{3}{4}$	3″	5.77

To find the amount of loose Amiesite necessary for any compressed thickness, subtract $\frac{1}{2}$ inch from compressed thickness, multiply by $1\frac{1}{2}$ which equals loose thickness, to which add 1 inch for Filler.

To find what compressed thickness any given amount of loose Amiesite will give, subtract 1 inch from loose thickness, multiply by $\frac{2}{3}$ and add $\frac{1}{2}$ inch for Filler.

TOPEKA MIX

The following data on output and organization is quoted from *Engineering Contracting.*

The wearing surface mixture was prepared in a Cummer standard 1-car portable paving plant of 2000 sq. yd. of 2-in. top per day (10 hours) rated capacity, having a twin-pug mill (10 cu. ft.) capable of handling a 1000-lb. batch of material. The total weight of this plant ready for transporting is 100 tons.

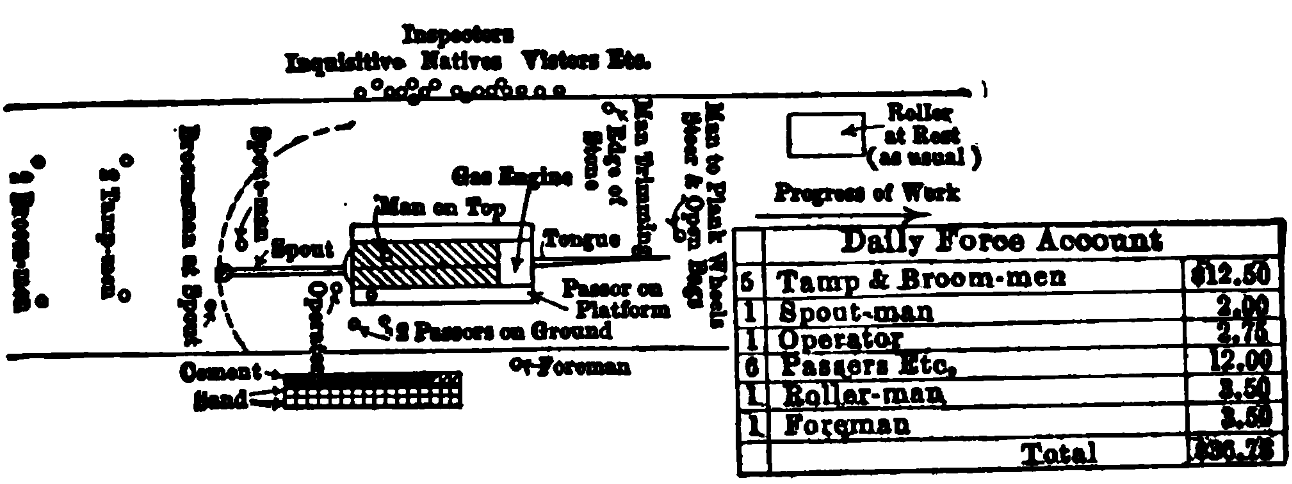
When the plant is working at its full capacity, 3 tons of coal are required per day.

The organization at the plant is as follows:

1 Foreman.
1 Engineer.
1 Fireman and 1 blacksmith.
2 Men at scales weighing materials.
2 Men feeding stone to elevator to drier.
2 Men feeding sand to elevator to drier.
2 Men shoveling stone from car.
2 Men shoveling sand from car.
2 Men stripping barrels, etc.
1 Man with horse, conveying sand from pile to elevator.
1 Man with horse, conveying stone from car to elevator.

On a good day's work (8 hours) the following quantities of material were used: 16 tons of asphalt, 132 tons of stone, 47 tons of sand, 11 tons of dust or filler, making a total of 206 tons of mixture.

Hassam Concrete Pavement.—*Cost of Grouting.* Road No. 5529. Lyell Ave., Spencerport. Season 1915. E. E. Kidder, Eng. in charge. Road 16′ wide 5″ deep compacted measure and approx. 6 miles long. 9880 cu. yd. of Hassam were grouted in 71 working days with the organization shown in the figure below.



	Daily Force Account	
6	Tamp & Broom-men	$12.50
1	Spout-man	2.00
1	Operator	2.75
6	Passers Etc,	12.00
1	Roller-man	3.50
1	Foreman	3.50
	Total	$36.75

71 days @ $36.25 per day	$2573.75
Amount grouted....................	9880 cu. yd.
Cost of labor per cu. yd.	$0.26

Conditions.—Administration and superintendence good. Temper of crew rather bad as they were not receiving the wages that they expected to get for the first half of the job. Could have made a better record.

Speed of Work.—Averaged 450 lin. ft. per day.

Materials

Cement.—8500 bbl. used or an average of 0.86 bbl. per cu. yd. of Hassam. This varied from 0.75 in the beginning to 0.95 during the latter part of the work when a liberal spread of stone was used to compensate for rough grading and a desire to end the work before winter.

Sand.—Royalty on sand was $0.30 per load or $0.052 per cu. yd. of Hassam. Cost of haul corresponds to average costs given in previous cost data.

Stone.—16,050 tons of limestone 1¼″ to 3½″ in size were used. This amounts to 3250 lb. per cu. yd. compacted measure which is high for this grade of stone. This was due to a liberal use of stone over poorly shaped sub-grade and to excess depth where wet material was removed.

Water.—Metered supply. 70 gal. per cu. yd. of Hassam; this includes water for engines, leakage in a long line and considerable waste at the grout mixer.

Concrete Roads

Cost Data.—Rd. 5423, Hartland Medina Pt. 2. Season 1914. F. W. Bristow, Eng. in charge. 9550 cu. yd. 1 : 1½ : 3 concrete pavement laid 16′ wide 6″ deep.

Materials and Equipment

Cement.—Knickerbocker @ $1.18 net bags returned f.o.b. siding. 4 mile average haul.

Sand.—Excellent local sand. 1¾ mile haul.

Stone.—Local crushed stone (Medina Sandstone and granite ½″ to 2½″ in size) ¼ mile haul to crusher, 1 mile haul crusher to road.

Concrete Mixer.—Koehring with boom and bucket delivery ⅜ cu. yd. batch.

Speed of Work.—500 to 550 lin. ft. of road or 148 to 165 cu. yd. mixed and placed per 10 hour day.

Actual Amount of Materials Used

Cement 1.85 bbl. per c. y. concrete
Sand 0.4 c. y. per c. y. concrete
Stone 0.80 c. y. per c. y. concrete

Joints

Wooden joints used for ½ the work.
Steel and felt joints used for ½ the work.

Labor Cost of Mixing and Placing Concrete

Labor $1.75 per 10-hour day.
The force at the mixer comprised:

1 Foreman.
2 Laborers setting forms.
10 " shoveling stone.
3 " " sand.
6 " on stone wheelbarrows.
" " sand

1 Laborer passing cement.
1 " emptying "
1 Mixer runner.
1 " fireman.
4 Laborers placing concrete.
2 " on screed.
2 " floating.
1 " preparing joints.
1 " sprinkling, brooming, etc.

The cost of setting forms, mixing, placing and finishing the concrete including coal ranged from 0.48 to 0.51 per cu. yd.

This does not include overhead or plant charge.

The water cost per cu. yd. concrete was approx. \$0.04 and includes laying pipe line and pumping from creeks.

The overhead charge per cu. yd. of concrete was approx. as follows:

Bond	\$0.036	per cu. yd.
Employers Compensation Insurance \$2.92 per \$100 payroll	0.096	" " "
Public Liability Insurance	0.016	" " "
Machinery and tools, freight hauling, erection, interest, depreciation and repairs	0.600	" " "
	\$0.748	
Say	\$0.75	per cu. yd.

COST DATA, CONCRETE ROADS

Materials

Stone.—Cost of stone varied greatly during the year, from 62¢ to 85¢ per cu. yd. at the Blissville docks. To obtain a low voidage contractors ordered a mixture of No. 2 and No. 3 stone. This mixture weighed approximately 2700 lb. per cu. yd.; therefore, cost of stone f.o.b. car at destination would be

1 cu. yd. stone at Blissville (say)	\$0.80
Transfer (17¢ per ton), 1.35 × 0.17	0.23
Freight (63¢ per ton), 1.35 × 0.63, (rate to Patchogue)	0.85
Total	\$1.88

NOTE.—Arrigoni paid \$1.81 delivered f.o.b., on rate made in 1914, before stone raised. Freight rate to Patchogue then 60¢.

Haul varied from 12¢ per yd. mile using tractor-roller and 5 cu. yd. trailers (3), to as high as 35¢ per yd. mile with teams.

Transfer from cars to wagons 15¢ to 20¢ per cu. yd. dependent mostly on rate of wages; therefore, cost on job, with stone as per above, and a two-mile haul would be approximately \$1.88 + 0.60 + 0.20 = \$2.68 per cu. yd.

Gravel.—Cost of same at bank, screened, and in bin varied from 45¢ to 85¢ (dependent mostly on per cent. of gravel). Haul: same as stone.

(*Continued page 612.*)

Lockport City, Market St. and Lake Ave. C.H. 1153

Length = 1.27 Miles
Width = 30′ — 47′

Asphalt Block Cost Data

Type: Asphalt Block
Medina Block

						Mortar Bed						Laying Block									
						Mixing				Placing and Striking											
Date	Station–Station	Lineal Feet	Square Yards	Hours Fore	Amount	Eng	Labs.	Amount	Bed men	Labs.	Amount	Layers	Amount	Cutters	Amount	Cull	Amount	Carry	Amount	Sand Cover	Amount
Nov. 16	67+70 67+87.2	87.2	270 Flare	8	$5.00	8	10	$5.50	8	35	$13.75	16	$10.00	...	...	5	$1.25	35	$8.75	.	.....
" 17	65+42 67+70	228	760	8	5.00	8	24	9.00	8	64	21.00	16	10.00	24	$6.00	24	6.00	56	14.00	...	.....
" 18	61+82 65+42	360	1200	8	5.00	8	32	11.00	16	72	28.00	32	20.00	40	10.00	16	4.00	112	28.00	32	$8.00
" 19	60+97 61+82	85 Olcott St.	284	8	5.00	2	8	2.76	4	14	6.00	10	6.25	10	2.50	2	.50	36	9.00	...	.....
" 20	57+85 60+97	312	1205	8	5.00	8	32	11.00	16	56	24.00	40	25.00	40	10.00	8	2.00	128	32.00	...	.....
" 21	53+95 57+85	390 Clinton St.	1300	8	5.00	8	32	11.00	16	56	24.00	40	25.00	40	10.00	8	2.00	112	28.00	..	...
" 22	51+60 53+95	235	1008	8	5.00	8	40	13.00	16	72	28.00	40	25.00	40	10.00	8	2.00	112	28.00	40	10.0
" 23	47+25 51+60	435 Flare St.	1450	8	5.00	8	40	13.00	16	72	28.00	40	25.00	40	10.00	8	2.00	112	28.00	40	10.00
" 24	44+75 47+25	315	1106	8	5.00	8	40	13.00	16	72	28.00	40	25.00	40	10.00	8	2.00	112	28.00	40	10.00
	35+00 35+65																				
" 25	31+60 35+00	340	1274	8	5.00	8	40	13.00	16	72	28.00	40	25.00	40	10.00	8	2.00	112	28.00	40	10.00
" 26	30+00 31+60	160	534	8	5.00	8	35	11.75	14	28	15.75	35	22.00	35	8.75	14	3.50	84	21.00	40	10.00
" 27	28+75 30+00	125 Adam St.	418	8	5.00	2½	12½	4.06	5	10	5.38	12½	7.81	12½	4.06	5	1.25	30	7.50	...	....

"	28	25+50	28+75	325	1192	8	5.00	8	40	13.00	16	32	18.00	40	25.00	40	10.00	16	4.00	96	24.12	40	10.00
"	29	24+15	25+50	135	450	8	5.00	4	20	6.50	8	48	17.00	16	10.00	20	5.00	8	2.00	48	12.00	80	20.00
"	30	21+55	24+15	260	870	8	5.00	8	32	11.00	8	24	11.00	16	10.00	40	10.00	...	...	96	24.00	40	10.00
Dec.	1	20+36	21+55	119	471	8	5.00	8	48	15.00	6	12	6.75	12	7.50	24	6.00	...	...	102	25.50	8	2.00
"	2	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	40	10.00
"	3	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	40	10.00
"	4	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	40	10.00
"	5	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	...	40	$10.00
					13776	128	80.00	112½	485½	163.57	189	443	302.63	445½	224.06	485½	122.31	138	34.50	1383	345.75	560	140.00

Total Cost
$1912.82

ASPHALT BLOCK
Engineer's Estimate

Block at Mfg. Plant, Lockport	= $0.96	sq. yd.
Haul ½ Mile	= 0.03	" "
Sand	= 0.02	" "
Cement	= 0.03	" "
On and off	= 0.04	" "
Lay and Roll	= 0.07	" "
Cushion	= 0.04	" "
	1.19	" "
Profit	= .18	" "
	1.37	" "
Use $1.40		

MORTAR BED { Mixing = 163.57 = $0.019 per sq. yd.
Paving = 302.63 = 0.022 " " "

Total Bed = 0.041 " " "

Estimate Based on Cost Data C.H. 1153

Blocks F.O.B. Lockport (Boots)	= $0.90	per sq. yd.
On and off	= 0.04	" " "
Haul ½ Mile	= 0.03	" " "
Sand	= 0.03	" " "
Cement	= 0.05	" " "
Lay	= 0.10	" " "
Mortar Bed	= 0.04	" " "
Carr'd For'd	1.19	" " "

BLOCK	Carrying	= 345.75	= $0.025	per sq. yd.
	Laying	= 724.06	= 0.053	" " "
	Cutting	= 122.31	= 0.009	" " "
	Culling	= 34.50	= 0.003	" " "
	Sand	= 140.00	= 0.010	" " "
	Total Cost		= 0.100	" " "

Bro't For'd	$1.19	per sq. yd.
Profit 10% Material	.10	" " "
" 20% Labor	.04	" " "
	$1.33	" " "

Contract Price $1.37

Sand.—Cost of same at bank (in wagons. Screening unnecessary) varied from 35¢ to 60¢.

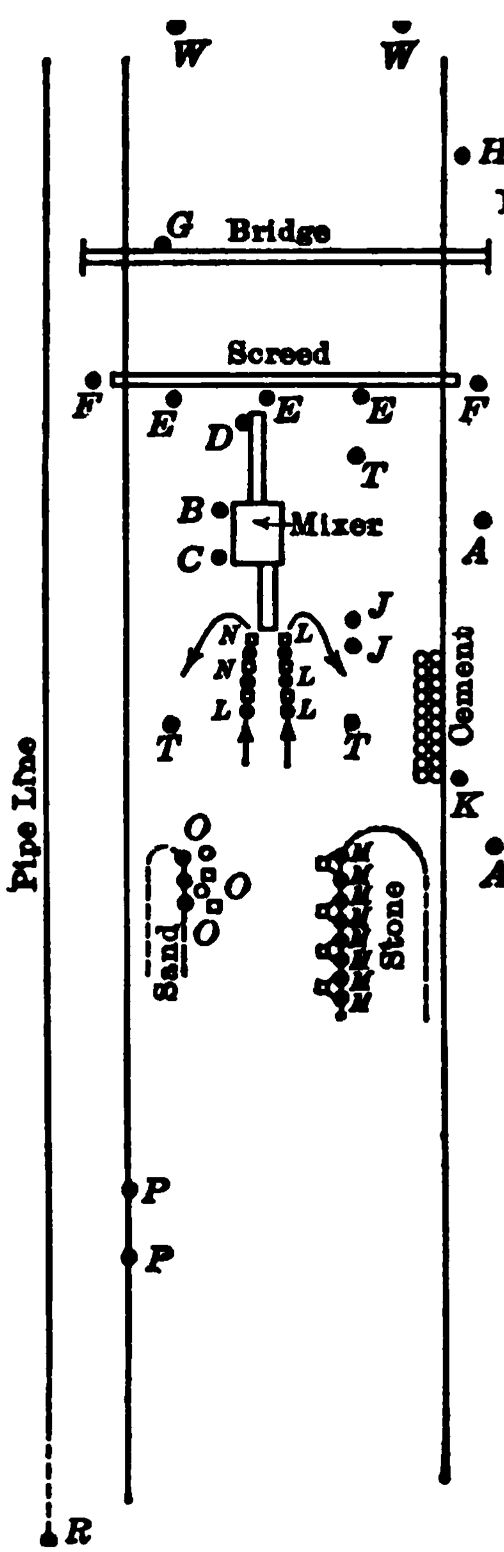
Haul: 25¢ to 35¢ per yd. mile.

NOTE.—When obtained from same pit as gravel I would consider its cost in bin as 1/3 the cost of all material leaving the plant, gravel in this case 2/3 of same total (say 25¢ [sand] and 50¢ [gravel] where gravel would be 75¢ + were all sand wasted).

Cement.—Cost of cement varied greatly during the year; a good average was $1.20 per bbl. net. Actual practice with graded stone has shown 1.75 bbl. per cu. yd. of concrete a safe factor.

Haul varied from 3½¢ (truck) to 5¢ (wagon) per bbl. mile.

Handling: average 2¢ per bbl. when handled direct from car to job.



Organization

Concrete 1-1½-3, 4 bag batch

Letter	Position	Number	Rate
A	Foreman	2	$3.00 & 4.00
B	Engineer	1	3.00
C	Fireman	1	2.50
D	Chute	1	2.00
E	Placing conc.	3	2.00
F	Screeding	2	2.00
G	Floating	1	2.50
H	Brooming and general help	1	1.85
J	Cement (to hopper)	2	2.00
K	Cement (getting ready)	1	1.85
L	Stone (barrows)	4 or 5	1.85
M	Stone (shoveling)	8	1.85
N	Sand (barrows)	2 or 3	1.85
O	Sand (shoveling)	3	1.85
P	Forms	2	2.00
R	Pump	1	2.25
T	Trimming grade	3	1.85
W	Watchmen, covering and wetting down	2	1.85

Also charge ½ Supt. and ½ timekeeper

Trimmers "*T*" place expansion joints

Plant.—Exclusive of forms and water-line.

1 Mixer—4 bag mix, 1–1½–3, at least 20 cu. ft. capacity.
1 Screed—19′ by 4″ by 12″, with ¼″ iron plate.
1 Bridge—18′ × 3″ × 12″.
3 floats—(one split); and one trowel.
1 doz. Forks—close tined for stone.
10 Square Shovels.
16 Wheel-barrows (2 or 2¼ cu. ft. capacity).
1 Canvass—160′ × 20′—with frame.
2 Tampers.
1 Template to test sub-grade.
1 doz. Pins to hold expansion joints (or special template for that purpose).
Small tools, other than noted.
1 Straight-edge, 24′ × 10″ × 4″, for extra width on curves.

Total cost of above approximately $2300.00.

Manipulation

Exclusive of water, forms and trimming sub-grade.

Supt. (½)	3.00
Time keeper (⅓)	1.00
Foremen (2) (see Fig., page 612)	7.00
Engineer (1) (" " , page 612)	3.00
Fireman (1) (" " , page 612)	2.50
Mason (1) (" " , page 612)	2.50
Laborers (8 at 2.00) (see Fig., page 612)	16.00
Laborers (21 at 1.85) (" " , page 612)	38.85
Total	$73.85

Based on an average day's work of 182 cu. yd. (10-hour day), the manipulation of a cubic yard of concrete would cost with the above organization, $0.406.

NOTE.—The above organization has laid over 780 lin. ft. of 16½ ft. pavement (outside dimensions), in a 10-hour day. (The 182 cu. yd. is based on a length of 600′ of pavement with a cross-section of 8.2 sq. ft.)

Water

Plant should be capable of supplying 30 gallons per minute.

Pipe: 10,000 (at least) lin. ft. 2″ pipe, galvanized at 16 cents	$1600.00
Black, at 14½ cents	1450.00
35 "Ts" for same (one each 300′) at 50¢	17.50

Pumps: 3 to 25 H.P., dependent on conditions. For lower power, gas engine O. K.; for higher, steam the best (latter, best for surety of supply).

Outfits $150.00 to $1000.00.

Where wells were necessary, 2″ supply pipe. Driving same $1.40 per ft. for depths not greater than 40′; $1.50 to 70′ depth. This includes pipe and point.

Shaughnessy paid a lump sum for water from Bayshore to Islip ($300.00, I believe) from hydrants. On 5232A, water was bought from private parties for part of the work at $3.00 per day.

Cost of running steam pump located at well or surface water supply, including operator, varies from $5.00 to $8.00 per day dependent on weather conditions.

200′ of rubber hose at $0.34 per ft. necessary for connection with mixer and sprinkling road. Of this a 15-foot section should be connected on intake pipe of mixer, with which to sprinkle sub-grade.

Forms

1. 6″ Channel forms (steel) 32¢ per ft. including pins, 8′ sections.
2. Patent steel forms with bevel, 24¢ per ft. Pins for same $1.00 each, one necessary for each section. Sections 12′ long.
3. Wooden forms with bevel about 12 cents per lin. ft.

Cost of placing same, 2 men at $2.00 per day, $4.00 per day (see "P," Fig., page 612).

At least 1200 ft. of forms necessary, so that 600 lin. ft. of road can be built without forms being moved. Based on (2) forms would cost

1200′ of forms	$288.00
Say 110 pins	110.00
Total	$398.00

Trimming Sub-grade

Three men generally necessary at $1.85 per day (see T, Fig., page 612).

General

A steam roller ($2200.00) might justly be, partially at least, charged to concrete. Cost of operating same, including rollerman, not greater than $12.00 per day if owned by contractor.

CONCRETE COST DATA

Name of Road, Main Street, Sec. III, County Highway No. 130. (Erie County, New York State)

Length, 3.68 miles. Thickness, average 7″ parabolic crown.
Width, 16′. Proportions of mix, 1–1½–3.
Total No. Cu. Yd., 7038.

1.	Labor, exclusive of water supply, including supervision	0.6818
2.	Plant forms and tools	0.3091
3.	Expansion joint material (Steel plates 0.1782; Tarred paper 0.0295; 0.2077)	0.2077
4.	Water supply, including labor	0.0625
5.	Cement placed on roadside ready for mixer	2.3379
6.	Sand " " " " " "	0.8359
7.	Stone " " " " " "	1.0518
8.	Reinforcement, if any	0.0000
	Total cost per cu. yd	5.4867

Labor, rate per hour, 16½¢; Teams, rate per hour, 50¢; Hours in day worked, 10.

Remarks: Work done by State day Labor. Materials unloaded by hand. Plant Charges included proportionate to life of plant. Seven-tenths mile average haul.

Name of Road, Huntington-Amityville, Pt. 2, No. 1219 (Suffolk County).

Length, 4.69 miles. Thickness, 4¾″ and 6¾″ = av. 5¾″.
Width, 16′. Proportions of mix, 1–1½–3.
Total No. Cu. Yd., 7409.

1. Labor, exclusive of water supply, including supervision	$0.52
2. Plant forms and tools	0.58
3. Expansion joint material	0.05
4. Water supply, including labor	0.10
5. Cement placed on roadside ready for mixer	2.36
6. Sand " " " " " "	0.23
7. Stone Gravel " " " " "	1.05
8. Reinforcement, if any	0.00
Total per cu. yd	$4.89
Contractor's Bid Price	5.30

Labor, rate per hour, 20¢; Teams, rate per hour, 55¢; Hours in day worked, 10.

Remarks: Auto truck for most of haul. Gravel furnished by large screening and washing plant accounts for high plant cost. Only proportionate part charged for this plant as it is to be used to produce commercial output.

Road No. 1201—Nassau County

(1) *Sand:*

In bins Heling Bros. per cu. yd	$0.15
Haul by auto (contractor owner) 2½ mi. at 0.15	0.38
Sand on road per cu. yd	0.53

Gravel:

In bins Heling Bros. per cu. yd	0.85
Haul by auto (contractor owner) 2½ mi. at 0.15	0.38
Gravel on road per cu. yd	$1.23

Cement:

Cement stored at $1.00 per day for 150 days	$150.00
Approximately 1170 bbl. stored. Storage per bbl.	0.13
F.o.b. Farmingdale (est.)	1.30
Handling and hauling (0.10 est.) double handling in most cases	0.10
Cement per bbl. on road	$1.53

This price also approx. cost of cement bought from Parker, Hassam Co.

Plant:

(2)	1 auto truck (Sauer)	$6,500.00
	1 Concrete mixer	1,200.00
	2 doz. shovels	21.00
	2 teams at $700, 2 bottom dumpers at $400	2,200.00
	Forms (wooden) 800 lin. ft.	40.00
	8 barrows	24.00
	2 doz. picks	42.00
	1 bucket conveyor, loader	600.00
	1 Screed	15.00
	Incidentals	20.00
		$10,672.00
(3)	Pressure water from fire plugs	
	Pavement per cu. yd. conc. 0.10	$100.00
	1500 ft. (lin.) 2″ pipe at 0.08	120.00
	100 ft. 2″ rubber hose	50.00
	300 ft. 1″ rubber hose	45.00
		$315.00
(4)	Manipulation per cu. yd. in place. This does not include covering, uncovering, sprinkling	$0.92
(5)	*Forms:*	
	Setting and re-setting forms per lin. ft. of road.	$0.03

$$\frac{3 \times 1.75 \times 20 \text{ days}}{3093} = 0.03$$

(6) *Trimming:*

Per cu. yd. of concrete $0.28

6 men @$ 1.75 20 days = $210
roller @ 12.00 6 " = 72

$$\frac{\$282}{990} = 0.28$$

cu. yd. of conc.

Expansion joints at 40¢ apiece every 30 ft.
Covering and uncovering and wetting concrete during curing season

2 men to cover @ $1.75	$3.50
2 men to uncover at $1.75	3.50
1 man to sprinkle	1.75
	$8.75

$$\frac{8.75 \times 20}{990} = \$0.18 \text{ per cu. yd. conc.}$$

Road No. 1203—Nassau County

(1) *Sand:*

In Pit of Mr. Bennett per cu. yd.	$0.15
Screening and loading (estimated)	0.22
Haul 2 mi. (auto truck) contractor owner @ 0.12	0.24
Cost per cu. yd. on road	$0.61

Trap Rock (Imported)

F.o.b. Baldwin $1.59 per cu. yd	$1.59
Unloading 15¢	0.15
Haul 1.6 mi. at 25¢ teams and auto truck	0.40
Stone per cu. yd. on road	$2.14
Cement:	
F.o.b. Baldwin per bbl.	$1.38
Handling and hauling per bbl. 0.05	0.05
Cement per bbl. on road	$1.43
(2) *Plant:*	
1 Screed	$ 20.00
1 Concrete Mixer	1800.00
1 Steam Roller	3000.00
1 doz. Wheelbarrows	36.00
2 doz. Shovels	21.00
3 Teams at $700, 3 Bottom Dumpers at $400	3300.00
1 Auto Truck	5000.00
2 doz. Picks	42.00
Forms (wooden $20.00; steel $126.00)	146.00
Incidentals	50.00
Water Wagon	400.00
	$13,815.00
Water:	
Pressure line fire plugs, total	$100.00
4000 ft. 2″ pipe .06	240.00
100 " " rubber hose	50.00
300 " 1″ " "	45.00
	$435.00
(4) *Manipulation:*	
Includes all works, sprinkling, covering, uncovering, in place complete per cu. yd	$0.67
(5) *Forms:*	
Setting and resetting forms per lin. ft. of road.	0.05
(6) *Trimming* (Sub-grade)	
Per cu. yd. concrete in place	0.24
Expansion Joints at 40¢. apiece every 30 ft.	

Road No. 1219.—Suffolk County

(1) *Sand:*	
In bins Heling Bros. pit cu. yd	$0.10
Haul by auto (contract) 1.5 mi. est. 0.30	0.30
Cost per cu. yd. on road	$0.40
Gravel:	
In bins Heling Bros. pit cu. yd.	$0.75
Haul by auto (contract) estimated 0.30	0.30
Cost per cu. yd. on road	$1.05
Cement:	
Bbl. f.o.b. Farmingdale	$1.27
Handling and hauling	0.08
Cement on road per bbl.	$1.35

(2) *Plant:*

Same as on No. 1218

(3) *Water:*

Cost of water	$700.00
1 mile 2" pipe at 0.06 per ft.	320.00
100 ft. 2" rubber hose	50.00
400 ft. 1" " "	60.00
1 pump and gas engine (est.)	1000.00
	$2130.00

(4) *Manipulation:*

Includes all work; sprinkling, covering, uncovering, in place complete per cu. yd.	$0.50
(5) Forms, setting and resetting per lin. ft. of road	0.02

(6) *Trimming:*

Per lin. ft. of road	0.06
Expansion joints at 40¢ apiece every 30 ft.	

Road No. 1218—Suffolk County

(1) *Sand:*

In bins Heling Bros. pit cu. yd.	$0.10
Haul by auto (by contract) 1.7 mi. approx.	0.40
Sand per cu. yd. on road	$0.50

Gravel:

In bins Heling Bros. pit cu. yd.	$0.75
Haul by auto (by contract) approx.	0.40
Cost per cu. yd. on road	$1.15

Cement:

F.o.b. Farmingdale	$1.27
Handling and hauling	0.08
Cement on road per bbl.	$1.35

(2) *Plant:*

Gravel and sand screening complete, including various set ups	$15,000.00
1 Concrete Mixer	1,800.00
1 Roller	2,800.00
1 Screed	20.00
18 Wheelbarrows	54.00
2 doz. Shovels	21.00
3 teams @ $700, 3 bottom dumpers @ $400	3,300.00
2 doz. Picks	42.00
1 rd. Planer and Scarifier	600.00
Forms (steel)	630.00
Tarpaulins	100.00
Incidentals	75.00
	$24,442.00

(3) *Water:*

Total paid for water approx.	$130.00
1 mile 2" pipe at 0.06	320.00
100 ft. 2" rubber hose	50.00
400 ft. 1" " "	60.00
	$560.00

(4) *Manipulation:*

Includes all work, sprinkling, covering, uncovering, in place complete per cu. yd.	$0.54

(5) *Forms:*

Setting and resetting forms per lin. ft. of road..	0.02

(6) *Trimming:*

Per lin. ft. of road	0.06

Expansion joints 40¢ apiece every 30 feet.

COST DATA

Name of Road, Huntington Town Line-Farmingdale, Part 1 (Suffolk County)

Length, 1.27 miles. Thickness, 5" & 7" = Av. 6".
Width, 16'. Proportions of mix, 1-1½-3.
Total No. Cu. Yd. 2051.

1.	Labor, exclusive of water supply, including supervision..	$0.56
2.	Plant forms and tools	0.61
3.	Expansion joint material	0.06
4.	Water supply, including labor	0.12
5.	Cement, Placed on roadside ready for mixer	2.13
6.	Sand, " " " " " "	0.22
7.	Stone, " " " " " "	1.01
8.	Reinforcement, if any	0.00
	Total per cu. yd	$4.71
	Contractor's Bid Price	5.30

Labor, rate per hour, 20¢; Teams, rate per hour, 55¢; Hours in day worked 10.

Remarks: Auto truck for most of haul. Gravel furnished by large screening and washing plant accounts for high plant cost. Only proportionate part charged for this plant as it is to be used to produce commercial output.

Road No. 1202—Nassau County

(1) *Sand:*

Estimated at 0.10 per cu. yd. in bins	$0.10
Haul (by contract) estimated at 0.40 per cu. yd....	0.40
	$0.50

Gravel:

Stiff leg derrick set up (in bins)	$2.00
Haul (by contract) estimated at 0.40 per cu. yd....	0.40
1st set up per cu. yd. on road	$2.40

Drag line set up per cu. yd.	$1.20
Haul (by contract) estimated 0.40 per cu. yd.	0.40
2nd set up per cu. yd. on road	$1.60

Imported gravel per cu. yd. scow L. I. City	0.85
Unloading from scow L. I. City	0.15
Freight L. I. City to Central Park	0.78
Unloading at Central Park	0.10
Haul (by contract) at 0.20 per cu. yd.	0.20
Cost per cu. yd. on road	$2.08

Average cost per cu. yd. on road $1.92.

Cement:

Bbl. f.o.b. Central Park {estimated by market}	$1.20
Haul by contract per. bbl.	0.06
Handling	0.02
Per bbl. on road	$1.28

(2) *Plant* estimated $12,000.00

(3) *Water:*

Cost of water	$1,000.00
4 mile 2" pipe at $0.06 per ft.	1,270.00
100 ft. 2" rubber hose at $0.50	50.00
400 ft. 1" " " $0.15	60.00
1 pump, boiler, etc.	1,000.00
	$3,380.00

(4) *Manipulation:*
Includes all work, sprinkling, covering and uncovering; in place complete per cu. yd. $0.64

(5) *Forms:*
Setting and taking up per lin. ft. of road 0.04

(6) *Trimming:*
Per lin. ft. of road 0.075
Expansion joints at 40¢ apiece every 30 ft.

COST DATA

Name of Road, Little Valley-Cattaraugus, Part 1 (Cattaraugus County)

Length, 5.35 miles. {3900 lin. ft. 16 ft. / 9700 " " 14 ft.}
Thickness, {6" & 8" = Av. 7". / 5¼" & 7" = Av. 6⅛".}
2.575 miles completed.

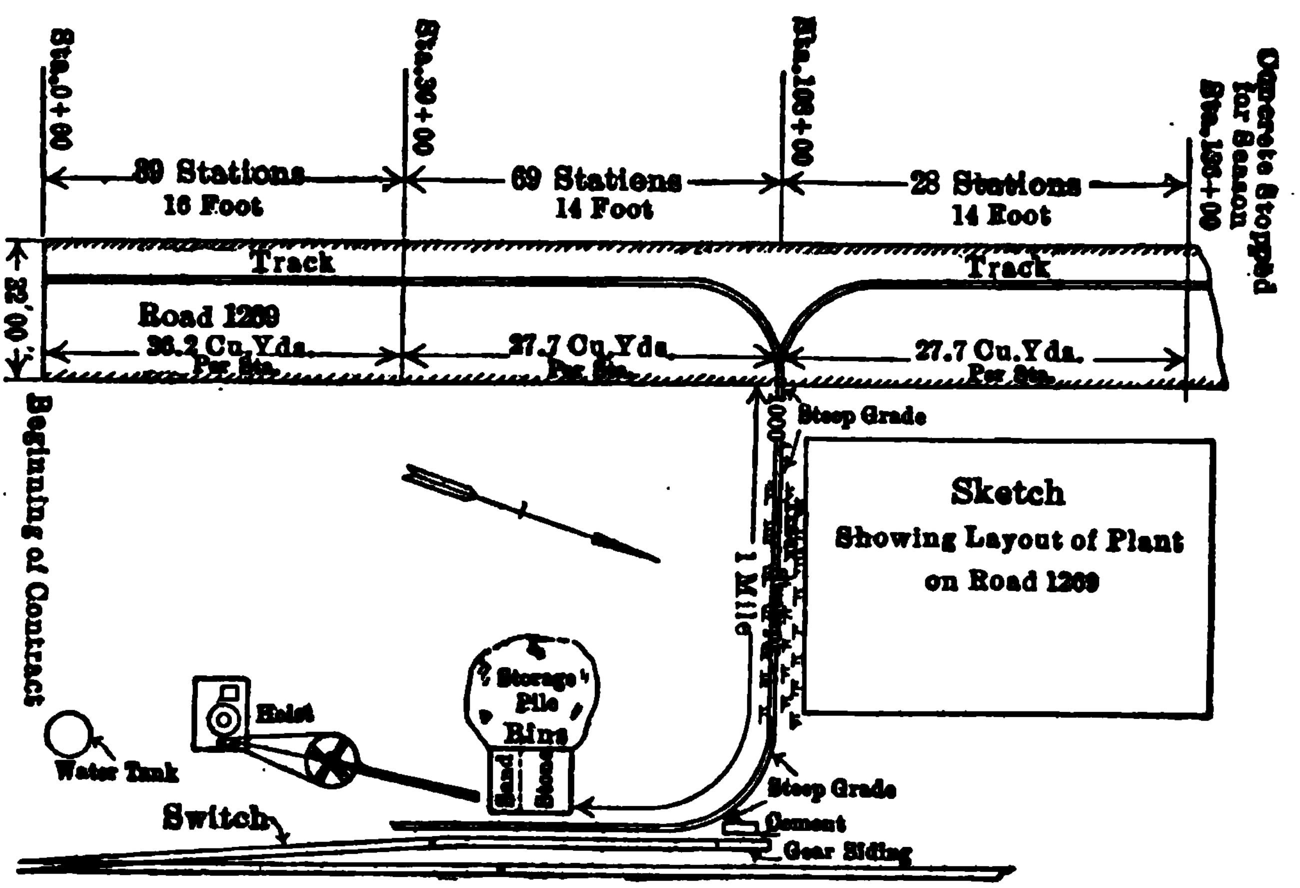
Width, 16 and 14. Proportions of mix. 1–1½–3.
Total No. Cu. Yd. 8280—This cost covers 4165 cu. yd.

1. Labor, exclusive of water supply, including supervision	0.423
2. Plant forms and tools. 0.662 + 0.158 for coal	0.820
3. Expansion joint material	0.045
4. Water supply, including labor	0.030
5. Cement, placed on roadside ready for mixer	1.984
6. Sand, " " " " " "	0.522
7. Stone, " " " " " "	1.505
8. Reinforcement, if any	0000
Total cost per cu. yd	5.324
Contractor's bid price	6.30

Labor, rate per hour, 18½¢; Teams, rate per hour, None used; Hours in day worked, 10.

Remarks: Industrial Ry. Plant delivering sand, stone and cement into hopper of concrete mixer, clam shell unloader used to take material off cars. Material delivered alongside mixer in buckets proportioned for one batch size.

For plant layout see illustration



COST OF CONCRETE WORK

The following data will help in estimating the cost of small concrete jobs, such as culverts, walls, etc. This data was collected by Mr. E. E. Kidder during the season of 1908. Table 62 contains the theoretical proportions of cement, sand, and stone required for the three ordinary mixtures of concrete. These values were found by experience to agree with actual proportions very closely for ½″ to 1¼″-stone. (Continued page 623.)

Little Valley-Cattaraugus Part I. — C. H. No. 1269

Cement Concrete Pavement. — 3900 Ft. of 6" and 8"-16 Ft. and 9700 Ft of 5½" and 7"-14 Ft.

Item	Amount	Amt. per Cu. Yd. Conc.	Amt. per Unit	Avg. Haul	Per Yd. Amount	Concrete Unload	Concrete Haul	Haul Yd. Mi.	Haul Ton Mi.	Unloading Yd	Unloading Ton	Remarks
Cement (Net)	$8036.00	$1.930	$1.00 bbl.	1.95 mi.	1.93 bbl.	.023	.031	.0565	.043	.082	.063	
Sand	1837.50	0.441	1.05 yd.	1.95 "	0.42 yd.	.035	.046					
Stone	5547.04	1.332	1.23 ton	1.95 "	0.9 yds.	.074	.099					
Joints	187.95	0.045	0.028 ft.									Includes Setting Forms, Covering and Watering Conc.
Manipulation	1764.00	0.423										
Unloading	549.50	0.132										
Hauling	735.00	0.176										
Coal (240 ton)	660.00	0.158	2.75 per ton	(Assumed)								
Water	124.92	0.030										

$4.667 — Cost per Cu. Yd. Excluding Cost of Plant. (See Below)

Plant

Hauling

Item	No.	Cost per	Amt.	
Dinkey Engines	3		2,500.00 Est.	Second Hand
Buckets	90	$6.50 each	585.00 Act'l	New (Wooden)
Track	20,000 ft.	0.26 ft.	5,200.00 "	Second Hand
Trucks	30	25.00 each	750.00 Est.	" "
Kopples	6	50.00 "	300.00 "	" "
			$9,335.00	

Note. Values attached to plant are estimated by Engineer where noted.

Unloading

Bins	1 Double	$1000.00 Est.	Pictures 1 and 2
Derrick and Hoist		1800.00 "	
		$2800.00	

Manipulation

Mixer (Austin Cube)	½ Yd.	$1900.00 New	Picture 5

Total Cost of Plant = $14,035.00

TABLE 62.—MATERIALS REQUIRED FOR 1 CU. YD. OF CONCRETE

Mixture	Cement	Sand	Stone
1–1½–3	1.9 bbls.	0.42 cu. yds.	0.85 cu. yds.
1–2–3	1.7 "	0.52 " "	0.77 " "
1–2–4	1.5 "	0.45 " "	0.90 " "
1–2½–5	1.2 "	0.46 " "	0.92 " "
1–3–6	1.0 "	0.47 " "	0.95 " "

The amount of water used per cu. yd. of concrete will vary greatly. A plastic mixture usually requires about 30 gals. per cu. yd., according to Baker, 40 gals. according to Barnes.

Where boulders are embedded in the foundations and side walls of small culverts similar to Plate 15, less cement, sand, and stone are required; our experience with work of this kind shows that only 0.8 to 0.9 bbls. of cement are needed per cu. yd. for the total amount of concrete in these culverts including cover and parapets. For all classes of work where boulders cannot be embedded these proportions are about right.

COST DATA SMALL CULVERTS

	Per Cu. Yd.
Forms (labor)	$0.58
Lumber	0.50
[1]Labor, mixing, and placing	1.18
[1]Foreman	0.20
[1]Broken stone, at crusher	0.90
[1]Hauling stone, one mile	0.30
Sand at pit at 65 cts. per cu. yd.	0.32
Hauling sand six miles	0.75
[1]Taking down forms	0.10
Cement at culverts	2.00
Total	$6.83

Labor, $0.15 per hour.
Concrete, hand-mixed.
200 cu. yd., placed in small culverts, averaging 12 to 15 cu. yd. each.

NOTE.—The labor of placing the concrete is customarily sublet to masons for $2.00 per cu. yd.

Small Culverts

Java Center Road. George A. Wellman, Engineer.

One hundred and sixty-one cu. yd. of concrete in culverts, averaging 12 to 20 cu. yd. each.

Boulders were embedded in the third-class concrete. Water only had to be hauled for 30 cu. yd. of concrete.

[1] Items accurate; other items approximately correct.

Item	Total Quality	Materials: Unit Cost	Materials: Total Cost	Amt. per Cu. Yd. of concrete: Material	Amt. per Cu. Yd. of concrete: Costs
Cement	138 bbl.	$1.12	$154.56	0.86 bbl.	$0.96
[1]Sand	60 cu. yd.	1.00	60.00	0.37 cu. yd.	0.37
Crushed stone	130 " "	1.55	201.50	0.80 " "	1.24
Lumber	3 M	30.00	90.00		0.56
				Total	$3.13

Costs are f.o.b. unloading point; teaming of material included in the labor cost given below, except for sand, which cost $1.00 delivered on the job. Concrete mixed and placed by hand.

Cost of Labor and Teaming

Item	Total	Per Cu. Yd. of Concrete
Foreman	$93.00	$0.58
Labor, unloading stone from cars	20.00	0.12
Mixing, placing concrete, and removing forms	204.00	1.27
Carpenters, building forms	75.00	0.47
Teaming	182.00	1.13
Total Labor		$3.57
Total Material		3.13
Total		$6.70

Labor	$0.175 per hour
Teams	0.50 " "
Carpenters	0.25 " "
Foreman	0.30 " "

Small Span Concrete Arch.—The following information of cost of 19-ft. span concrete arch was given by Mr. Charles M. Edwards, First Assistant Engineer, New York State Department of Highways. Arch was built at Pembroke, N. Y., by a contractor who was crushing stone at a quarry about one-half mile from the work. Cement was hauled three-quarters of a mile. For the concrete a mixture of one part Portland cement, two parts sand, and four parts stone was used. The old masonry abutments and wings were left in place and faced with 8 inches of concrete held by dowels. The quantities were: Concrete, 120 cu. yd.; steel bars, 4500 lb.; pipe railing, 200 lin. feet. The cost of the work was as follows:

[1] The sand on this job cost practically nothing but we have placed the cost at $1.00 in order to avoid a misleading item.

Lumber, including arch centers	$156.00 on job
Steel	106.00 " "
Cement	137.00 on siding, f.o.b.
Stone	240.00 on job
Dust and sand	90.00
Railing	78.00 f.o.b. siding
Labor	300.00
Total	$1107.00

Omitting the cost of railing this figure gives a cost of $8.57 per cu. yd. of concrete, including steel. This cost does not include salvage of lumber or overhead expenses of any kind. The contractor received $1500.00 for the work, including the earth filling, for which he used quarry strippings. This filling cost about $50.00.

Guard-Rail.—In the following data the labor cost alone is given, for the materials will vary so much at different times and places that any quotations would be of little value.

The style of rail erected is similar to sketch, page 216. Road 715, 9760 lin. ft. were built at the following cost, according to S. O. Steere, engineer in charge: Post-hole auger-diggers and ordinary shovels were used; the holes were dug in medium hard clay; labor at $0.20 per hour, foreman $3.00 per day; unskilled labor used in painting fence.

Digging post holes, setting posts, nailing on rails (erecting fence complete):

Cost	$0.0428 per lin. ft.
Painting three coats	0.0094 " " "
Total for erecting and painting	$0.0522 " " "

Road 5046, W. G. Harger, as Engineer. 2448 lin. ft. Built by subcontractor, Max Weller.

Force: Max Weller acted as foreman. In this data he has been arbitrarily allowed salary of $4.00 per day $4.00

1 helper	2.50
1 "	2.00
1 "	1.75

Cost of erecting and painting complete, per lin. ft. $0.066.

Guard-Rail Paint

15 lb. white lead
¾ gal. oil } 1 gal paint.

25 to 30 lb. white lead and 1½ gal. oil to paint 100 ft. guard-rail 3 coats.

In Report of 1901 the Massachusetts Highway Commission gives the following costs for repainting guard-rail:

Lineal feet of guard-rail painted	350,330
Cost of paint per gal. (freight not included)	$ 1.05
Cost of paint per lin. ft. of guard-rail	0.0084
Cost of paint and painting per lin. ft. of guard-rail	0.0165
Lin. ft. of guard-rail painted per gal.	134.4
No. gal. of paint used per lin. ft. of guard-rail	0.0077
Time required to paint one foot, in decimals of an hour	0.0269

Concrete Guard-Rail.—Style of rail shown in sketch on page 217, chapter on Minor Points.

Labor, $0.225 per hour.

Cost of manufacturing 1233 lin. ft. of rail of the above description. Taken from the Report of the New York State Highway Commission of 1910.

Lumber	$ 32.46	$0.026 per lin. foot
Steel	139.64	0.114 " " "
Cement	57.62	0.046 " " "
Gravel	10.00	0.008 " " "
Metal cores	77.00	0.063 " " "
Labor	231.83	0.188 " " "
Miscellaneous	5.35	0.004 " " "
Total	$553.90	0.449

This data applies to small quantities; if manufactured on a large scale the cost should be reduced to about $0.30 per lin. ft.

The cost of setting the above rail varied from $0.09 to $0.125 per lin. ft.: labor $0.225 per hour. This does not include hauling from the factory to the intended position on the road.

Cobble Gutter.—Road 5046, W. G. Harger, Engineer.

Labor, $0.175 per hour. Foreman, $3.50 per day.

Cobbles averaged 6 in. in size; no sand cushion required, as gutter was built in a sand cut. Gutter was laid by ordinary laborers using paver's tools; tamped with a paving rammer, and the top voids filled with No. 2 stone crushed on the job.

430 sq. yd. were laid at the following cost per sq. yd.:

Cobbles, free	$0.000
Loading 1/6 cu. yd. of cobbles	0.030
Hauling 1/6 " " " " 1/2 mile	0.024
Laying and tamping	0.080
Filler.—Cost of 0.05 cu. yd. No. 2 stone at crusher bin, approximately	0.030
Hauling 0.05 cu. yd. 1 mile	0.015
Spreading and brooming, 0.05 per cu. yd. No. 2 stone	0.010
Total	$0.189

PRICES OF VITRIFIED PIPE

The discounts vary, but if no quotations of current prices are available the following list will serve for an approximate estimate:

[1] Eastern List 1912

Size	Discount
3" to 24"	88%
24" and 30"	80%
33" and 36"	75%

At these discounts the net prices per foot in car-load lots f.o.b. factory are:

Size	Price	Size	Price
3"	$0.024	20"	$0.270
4"	0.030	21"	0.325
5"	0.036	22"	0.360
6"	0.048	24"	0.390
8"	0.066	27"	0.900
10"	0.096	30"	1.100
12"	0.120	33"	1.560
15"	0.162	36"	1.750
18"	0.227	—	—

PLANT AND PAYROLL

Table 63, page 628, shows in a convenient form the value of plants and the largest weekly force account of two months' duration on fourteen roads in New York State. From this and other information it is reasonable to assume that a contractor has tied up, outside of money on plant and materials, from $5000 to $8000 for the full length of time that the work is in progress, and for short periods he may have as high as $15,000 or $20,000 invested.

Interest, Depreciation, Repairs, etc.—To the best of my judgment the following estimates show about the amount of money required on the different styles of construction noted. These data are based on an outfit which would be capable of a speed of about 0.7 mile per month, or five miles in a season.

Charge for bond ¼ of 1% total contract in 1916. There is considerable fluctuation in this and the liability insurance rates. Use the prevailing rate for your conditions. The rates given in the following estimate forms are for New York State conditions in 1916.

[1] *Engineering News*, April 4, 1912.

TABLE 63.—SPEED OF WORK, VALUE OF PLANT, FORCE ACCOUNT. SUMMARY OF PLANTS AND FORCE ACCOUNTS

Road No.	Style of Road	Local or Imported Stone	Kind of Hauling	Weekly Force Account	Value of Plant	Speed of Work Miles per Month
1	16-ft. Bit. Mac.	Imported	Mechanical and teams	$1,000	$13,500	0.7
2	16 " " "	"	Mechanical	800	13,600	0.7
3	16 " " "	"	Teams	900	8,000	0.5
4	16 " " "	"	"	1,000	8,000	0.6
5	16 " " "	"	"	—	4,500	0.4
6	16 " " "	" top (local bot.)	"	1,900	14,500	1.3
7	16 " " "	Local	Teams and Mechanical	600	12,000	0.5
8	16 " " "	"	Teams	1,000	9,000	0.5
9	16 " " "	"	"	600	9,000	0.6
10	16 " Water Mac ..	"	"	1,600	10,000	1.2
11	16 " " " ...	"	"	1,000	10,500	0.8
12	16 " " " ...	Imported	"	1,000	6,000	0.7
13	14 " " " ...	"	"	1,200	12,600	0.7
14	16 Resurfacing	"		500	5,000	1.5

Labor, $0.16 to $0.20 per hour. Average $0.175. Teams, $0.40 to $0.50 per hour. Average $0.45.

Adopted Value of Plant Items

Item	Value	Life	Annual Repairs
10-ton roller	$2700	20 yrs.	$70.00
Brick roller	1800	20 "	40.00
Traction-engine	1200	8 "	100.00
Crusher	900		
Elevator	200	8 "	400.00
Bin and screen	500		
5 H.P. gasoline engine	250	8 "	50.00
Gas engine and pump	200	5 "	50.00
6000 ft. of pipe	600	say 10 "	10.00
Wagons	115	6 "	10.00
Hand tools	150	1 "	—
Plows	100	3 "	—
Road machine	200	5 "	10.00
Tar kettle	$125–200	—	[1] 10.00
Wheel scraper	70	5 "	10.00
Slush scraper	6	5 "	—
10-ton roller used for hauling	2700	10 "	200.00
Hauling traction-engine	2200	8 "	200.00

[1] Including new tank every three years.

6% Interest and Depreciation on Plant Items

Item	Interest	Depreciation
Roller	$162.00	$135.00
Traction-engine	72.00	150.00
Crusher	54.00	100.00
Elevator	12.00	30.00
Screen	3.00	50.00
Bin	30.00	40.00
Gasoline engine	15.00	30.00
Gasoline pump	12.00	40.00
6000 feet 1½" pipe	36.00	60.00
Wagons	6.00	20.00
Hand tools	9.00	150.00
Plows	6.00	30.00
Tar kettle	12.00	10.00
Concrete mixer	120.00	—
Brick roller	108.00	100.00
Wheel scrapers	5.00	15.00
Slush scrapers	—	—
Roller used for hauling	162.00	270.00
Hauling engine	132.00	300.00

Charge for bond ¼ of 1% total contract in 1916. There is considerable fluctuation in this and the liability insurance rates. Use the prevailing rate for your conditions. The rates given in the following estimate form are for New York State conditions in 1916.

PLANT FOR WATERBOUND MACADAM IMPORTED STONE

Elevator unloading plant, provided more than 2000 cu. yd. of stone is to be unloaded.

Item	Interest	Depreciation	Repairs
Elevator	$12.00	$30.00	$50.00
Bin	30.00	40.00	50.00
5 H.P. gasoline engine	15.00	30.00	50.00
1 roller with broom and sprinkling attachment	162.00	135.00	70.00
6000 ft. 1½" pipe	36.00	60.00	10.00
Gasoline engine and pump	12.00	40.00	50.00
Hand tools	9.00	150.00	—
Plows	6.00	30.00	—
Road machine	12.00	40.00	10.00
2 wheel scrapers	5.00	15.00	10.00
2 slush scrapers	—	—	—
15 wagons	80.00	300.00	150.00
Totals one season's work 5 miles	$379.00	$870.00	$450.00
Total per mile	76.00	174.00	90.00

Force account money out: Allow six weeks out continually for length of job at ½% interest per month.

Allow $6000 out, or $40.00 interest per mile on force account.

Bond charge: ¼ of 1% contract price; approximately $25.00 per mile. Insurance charge: $2.00 per $100.00 total force account, approximately $100.00 per mile.

Allow for moving plant on job, $500.00 lump sum.

Plant for Waterbound Macadam Local Stone

Item	Interest	Depreciation	Repairs
1 traction engine	$ 72.00	$150.00	$100.00
1 crusher and bin	100.00	220.00	400.00
1 steam drill and bits	10.00	50.00	80.00
1 small boiler for drill	12.00	30.00	20.00
Roller, pipe, gasoline engine and pump, hand tools, plows, road machine, scrapers and wagons as for imported stone plant. Total of these items	322.00	770.00	300.00
Total for season, 5 miles	$516.00	$1220.00	$900.00
Total per mile	103.00	245.00	180.00

Force account slightly larger on local stone roads. Approximately $7000.00 out.

Interest on force account .... $50.00 per mile
Bond charge .... 20.00 " "
Insurance........................... 120.00 " "

Moving plant on job, $500.00 lump sum.

PLANT FOR BITUMINOUS MACADAM IMPORTED STONE

ITEM	Interest	Depreciation	Repairs
Elevator unloading plant	$60.00	$100.00	$150.00
2 rollers	320.00	270.00	140.00
3 tar kettles..................	36.00	—	30.00
Hand tools, plows, road machine, scrapers and wagons as for waterbound macadam. Total of these items	112.00	535.00	170.00
Total for season, 5 miles.....	$528.00	$905.00	$490.00
Total per mile..............	106.00	181.00	98.00

Interest on force account............. $ 40.00 per mile
Bond charge......................... 30.00 " "
Insurance........................... 100.00 " "

Moving plant on job, $500.00 lump sum.

PLANT FOR BITUMINOUS MACADAM LOCAL STONE

ITEM	Interest	Depreciation	Repairs
1 traction engine..............	$72.00	$150.00	$100.00
1 crusher outfit...............	100.00	220.00	400.00
1 steam drill and bits..........	10.00	50.00	80.00
1 portable boiler for drill.......	12.00	30.00	20.00
Rollers, hand tools, plows, road machine, scrapers, wagons, and tar kettles as for imported stone. Total of these items..	468.00	805.00	340.00
Total for the season, 5 miles..	$662.00	$1255.00	$940.00
Total per mile..............	132.00	251.00	188.00

Interest on force account............. $50.00 per mile
Bond charge......................... 25.00 " "
Insurance........................... 120.00 " "

Moving plant on job, $500.00 lump sum.

FORMS FOR ESTIMATES (Macadam Roads)

The following forms of estimate have proved very satisfactory. The item of 6% on materials is used to cover demurrage and interest on money tied up on freight and stone. The other items of profit are what we consider a reasonable return for the risk of such contract work. Mechanical hauling is not considered, because few contractors own plants that make it possible. The total item of interest, depreciation, repairs, and interest on force account money for the whole job is charged against top and bottom stone, as the construction quantities of the macadam will vary less from the estimated quantities than any other classes of work.

Standard Estimates.—Figured on the basis of 20% profit on labor, 6% on materials, 6% on money invested, and an allowance made for depreciation on different plants, as previously given.

Labor at $0.175 per hour
Teams at $0.450 " "

Earth Excavation.

Class	Amount per Mile	Price per Cu. Yd.
Easy	5,000–10,000 cu. yds.	$0.40
Easy	3,000– 5,000 cu. yds.	0.45
Easy	1,500– 3,000 " "	0.50
Average	3,000– 5,000 " "	0.50
Average	1,500– 3,000 " "	0.60
Hard...........	3,000– 5,000 " "	0.60
Hard...........	1,500– 3,000 " "	0.70

Rock Excavation.

	Large boulders (for which 10 cu. yd. a mile are allowed on all estimates)..........	$1.50	per cu. yd.
1.	Steam drillwork, limestone........	$0.80 to 1.25	" " "
	" " granite..........	0.80 to 1.50	" " "
2.	Hand " limestone..............	2.00	" " "
	" " granite................	2.00	" " "

1. Large quantities.
2. Small quantities.

Field Stone Sub-base.

A sub-base course 6 in. deep made of the usual size fence stone requires 1 cu. yd. loose for 1 cu. yd. rolled; 12 in. deep requires 1.25 cu. yd. loose.

Cost of cobbles per loose cu. yd.	$0.10
Loading cobbles per loose cu. yd.	0.15
Hauling cobbles 1 mile per loose cu. yd.	0.35
Placing cobbles per loose cu. yd.	0.10
Rolling cobbles per loose cu. yd	0.05
Filler (see below)	—
Total	$ —
20% profit	—
Estimate	$ —

Multiply these items by 1.25 for 12-in. depth of sub-base.

Filler.

1/3 cu. yd. per cu. yd. rolled sub-base.

Cost 1/3 cu. yd. at pit or crusher	$ —
Loading 1/3 cu. yd.	0.05
Hauling 1/3 cu. yd. 1 mile	0.10
Spreading 1/3 cu. yd.	0.04
Total	$ —

Sub-base Bottom Course.

Same relation of loose and rolled quantities as for sub-base.

Cost fence stone per loose cu. yd.	$0.10
Loading fence stone per loose cu. yd.	0.15
Hauling 1 mile per loose cu. yd.	0.35
Placing and sledging	0.20
Rolling	0.05
Filler (see below)	—
Total	$ —
20% profit	—
Estimate	$ —

Filler.

1/3 cu. yd. per cu. yd. rolled sub-base.

Cost 1/3 cu. yd. at pit or crusher	$ —
Loading	0.05
Hauling 0.33 cu. yd. filler per mile	0.10
Spreading and brooming	0.08
Total	$ —

Imported Bottom Stone Materials.

3″ course, 3050[1] lb. f.o.b. crusher	$ —
4″ " 3150 " " "	—
6% profit	—
Total	—
Freight on stone to delivery point	—
Total, No. 1	$ —

[1] These weights are for limestone. See page 591.

Labor.

Unloading	
Under 2000 cu. yd. (shoveling)	$0.15 per cu. yd.
Over 2000 cu. yd. (elevator)	0.10 " " "
Hauling (Teams)	
Bad conditions	0.35 " " "
Average conditions	0.30 " " "
Good conditions	0.25 " " "
Mechanical hauling	0.15 " " "
Spreading	
5⅓ in. loose depth	0.06 " " "
4 in. loose depth	0.08 " " "
Rolling	0.05 " " "

At this point total up and add 30% of the total to change the estimate from loose to rolled measure.

Filler (see below)	———
Labor, total	$ —
20% profit	—
Total, No. 2	$ —

Filler.

Cost of 0.35 cu. yd. at pit or crusher	$ —
Loading 0.35 " "	0.05
Hauling 0.35 " " 1 mile @ $0.35 per yd. mile	0.12
Spreading and brooming 0.35 cu. yd	0.07
Filler, Total	$ —

Summary.

Total No. 1 (materials)	$ —
Total No. 2 (labor)	—
Interest and depreciation (see page 630)	—
Estimate	$ —

Imported Top Stone Waterbound Macadam Materials.

[1]4450 lb. stone f.o.b. (limestone)	$ —
6% profit	—
Total	$ —
Freight on stone to delivery point	—
Total No. 1	$ —

[1] These weights are for limestone. See page 591.

Labor.

Unloading (same as bottom)	$ —
Hauling (same as bottom)	$ —
Spreading	0.08
Rolling	0.04
Puddling	0.06
Total, loose measure	$ —
Add 30%	—
Total rolled measure	$ —
Screenings. (See below)	—
Total	$ —
20% profit	—
Total No. 2	$ —

Screenings.

Unloading[1]	0.5 cu. yd			$0.07
Hauling	0.5 "	"	1 mile	0.15
Spreading	0.5 "	"	by cross dump wagons	0.03
"	0.5 "	"	hand	0.07
Total				$ —

Summary.

Total No. 1 (materials)	$ —
Total No. 2 (labor)	—
Interest, depreciation, etc.	—
Estimate	$—

IMPORTED TOP STONE BITUMINOUS MACADAM. PENETRATION METHOD

Materials (per consolidated cu. yd.).

2″ course, 4350 lb. stone and screenings, f.o.b. crusher	$—
3″ " 4050 " " " " " "	—
gal. bituminous binder, f.o.b. plant	—
6% profit	—
Total	$—
Freight on materials to delivery point	—
Total No. 1 (materials)	$—

[1] Screenings are usually unloaded by hand.

Labor.

No. 3 stone (2½″ size)	
Unloading 1 cu. yd. (same as given page 634)	$—
Hauling 1 cu. yd. " " "	—
Spreading 1 cu. yd. " " "	—
Rolling 1 cu. yd.	0.09
Total	$—
Add 20% for 2″ course, 30% for 3″ course	—
Total No. 2	$—

No. 1A, No. 2, and Bitumen.

Unloading 0.6 cu. yd. for 2″ course (same as given)	$—
" 0.37 " " " 3″ " " " "	—
Hauling at the rate of $0.30 per yd. per mile	—
Hauling bitumen at rate of $0.002 per gal. per mile	—
Spreading and brooming No. 1A and No. 2 at rate of $0.30 per cu. yd.	—
Manipulation of heating and spreading bitumen at $0.015 per gal.	—
Total No. 3	$—
Total No. 2	—
Total	$—
Add 20% profit	—
Total No. 4	$—

Summary.

Total No. 1 (materials)	$ —
Total No. 4 (labor)	—
Interest, depreciation, etc.	—
Estimate	$ —

LOCAL STONE MACADAM

Field Stone.

1 cu. yd. field stone = 1 cu. yd. crushed.

1.8 cu. yd. field stone = 1 cu. yd. No. 3 and No. 4 rolled.

Cost of field stone		$0.10	per cu. yd.
Blasting or sledging, per cu. yd. actually blasted or sledged		0.40	" " "
Loading field stone		0.15	" " "
Hauling field stone 1 mile		0.35	" " "
Crushing		—	" " "
Sandstone (soft)	$0.10		" " "
Limestone	0.15		" " "
Granite and trap rock	0.20		" " "

Total cost in bins (loose including Nos. 1, 2, 3, and 4 stone) per cu. yd.	$—	“ “ “

Quarried Stone.

Limestone, quarrying, small quarries	$0.50	“ “ “
Conglomerate, “ “ “	0.75	“ “ “
Trap, “ “ “	0.65	“ “ “
Crushing (same as above)	—	“ “ “
Total cost in bins	$—	“ “ “

The crushing does not include repairs to crusher.
The crushing is taken from previously given data.
The item of quarrying includes delivery to crusher.

Estimate of Bottom Stone.

Cost in bins, per cu. yd.	$ —
Loading, per cu. yd.	0.01
Haul (same as bottom, page 634)	—
Spread (same as bottom)	—
Rolling (same as bottom)	—
Total (loose measure)	$ —
Add 30%	—
Total rolled measure	$ —
Filler (same as bottom)	—
20% profit	—
Total, No. 1	$ —
Interest and depreciation	—
Estimate	$ —

Local Top Stone.

Cost in bins, per cu. yd.	$ —
Manipulation same as for imported stone	—
Total	$ —
20% profit	—
Total No. 1	$ —
Interest and depreciation	—
Estimate	$ —

Imported No. 2 Stone, Estimated Loose

Material.

2400 lb. stone, per cu. yd.	$ —
6% profit	—
Total No. 1	$ —

Unloading (same as bottom)	—
Haul (same as bottom)	—
Spreading	0.10
Total	$ —
20% profit	—
Total No. 2	$ —
Total No. 1 (material)	$ —
Total No. 2 (labor)	—
Estimate	$ —

LOCAL NO. 2 STONE

Cost per cu. yd. in bins	$ —
Haul same as above	—
Spreading same as above	—
Total	$ —
20% profit	—
Estimate	$ —

The following is an example of the method of using these standard forms.

ESTIMATE FOR LOCAL FENCE STONE CRUSHED MACADAM BOTTOM COURSE

Assume that stone will cost $0.10 per cu. yd. in the fences.
" ½ mile average haul to crusher.
" 20% of the stone has to be sledged or blasted.
" ¾ of a mile average haul from the crusher.
" that filler costs $0.15 per cu. yd. in the pit.
" average haul of ¼ mile for filler.
" that the interest and depreciation charge for the total job, say 4 miles, is distributed over 6000 cu. yd. of macadam.

Use Standard form for Local Bottom Stone, given on page 636.

Cost 1 cu. yd. field stone	$0.10
Blasting and sledging ⅕ cu. yd. stone	0.08
Loading 1 cu. yd. field stone	0.15
Hauling 1 cu. yd. field stone ½ mile	0.18
Crushing 1 cu. yd. (Mixed granite and sandstone)	0.15
1 cu. yd. Total cost in bin	$0.66

Cost 1 cu. yd. crushed stone in bins	$0.66
Loading on wagons, per cu. yd.	0.01
Haul to road, average conditions, ¾ of a mile	0.22
Spreading 5⅓" loose, per cu. yd.	0.06
Rolling	0.05
Total	$1.00

Add 30%	0.30
Per. cu. yd. rolled measure	$1.30
Filler (see below)	0.31
Labor, total	$1.61
Add 20% profit	0.32
Total, No. 1	$1.93
Interest, depreciation, etc. (see below)	0.56
Estimate per cu. yd. rolled in place	$2.49

say $2.50.

Filler.—As mentioned on page 597, the screenings produced in crushing bottom only, as in this case, will amount only to 50% of the required filler, therefore two estimates must be made for filler as below:

Screenings for Filler.

Cost of 0.35 cu. yd. screenings in bin @ $0.66 per cu. yd.	$0.230
Loading 0.35 " " " from bin	0.003
Hauling 0.35 " " " ¾ of a mile	0.077
Spreading and brooming 0.35 cu. yd	0.070
Total	$0.380

Sand Filler.

Cost of sand in pit 0.35 cu. yd.	$0.052
Loading 0.35 cu. yd.	0.050
Hauling 0.35 " " ¼ mile (short-haul figures)	0.060
Spreading and brooming 0.35 cu. yd.	0.070
Total	$0.232

Average these costs as the screenings must be utilized to use up the total output of the crusher. Average filler $0.31.

Interest, Depreciation, etc.—From page 630, using value adopted for, say, waterbound macadam roads, the following charge for a 4-mile road is figured:

Interest on plant	4×103.00	$412.00
Depreciation on plant	4×245.00	980.00
Repairs on plant	4×180.00	720.00
Interest on payroll	4× 50.00	200.00
Bond charge	4× 20.00	80.00
Insurance	4×120.00	480.00
Moving plant on job		500.00
Total		$3372.00

to be spread over 6000 cu. yd. of macadam.

$$\frac{3372}{6000} = 0.56 \text{ cents per cu. yd.}$$

The cost of an improved highway generally depends on the item of top and bottom stone in place complete. Many of the minor items have standard prices. Such items as cast-iron pipe, the various sizes of tile, pipe railing, mesh reinforcement steel, etc., will hardly vary in price throughout the Eastern States. A table of these standard prices as used by the New York State Highway Commission is given below.

It will be noted that all of these items have little bearing on the total cost, and that the items of Earth Excavation, Sub-base, or Sub-base Bottom Course, Macadam Bottom and Top Course, Concrete Foundation, Brick Pavement, etc., which of necessity are not standard in price, determine whether or not the road is to be expensive.

UNIT PRICES MINOR ITEMS (Date 1915)

Overhaul on excavation	$ 0.01	per yd. sta
Third-class masonry cement joints	6.00	per cu. yd.
Second-class concrete	9.00	" " "
Third-class concrete (stone)	7.00	" " "
" " " (gravel)	5.50	" " "
Pointing old masonry	0.75	" sq. "
Riprap	1.50	" cu. "
Paving cement joints	1.50	" sq. "
Cobble gutter	0.50	" " "
Expanded metal	0.08	" " ft.
Guard-rail	0.30	" lin. ft.
2" pipe rail	1.50	" " "
Concrete guard-rail	1.00	" " "
Cast-iron pipe in place	35.00	" ton
6" V. T. P. in place	0.30	" lin. ft.
12" V. T. P. " "	0.60	" " "
15" V. T. P. " "	0.90	" " "
18" V. T. P. " "	1.10	" " "
24" V. T. P. " "	2.00	" " "
Relaying old pipe	0.10	" " "
4" farm tile under drain in place	0.10	" " "
Steel in place	0.05	" lb.
Oak timber in place	50.00	" M.B.M.
Hemlock timber in place	40.00	" M.B.M.
Danger signs	2.00	each
Guide-board posts	6.00	"
Highway No. signs	1.00	"
Guide signs per letter	0.15	"

The item of Earth Excavation as shown in Table 56 may vary between 40¢ and 65¢. In extreme cases where material is difficult to handle, it may be estimated still higher. A particular instance of costly excavation where 70¢ was estimated occurs on a road near the Lackawanna Steel Plant at Buffalo. This road had been filled with slag from time to time.

In the remaining variable items the length of haul is a governing factor and three actual conditions of determining the average haul are given here before proceeding farther with the estimate data.

The following cases 1, 2, and 3 show also the New York method of estimating where interest and depreciation are not directly considered.

Case I

The simplest possible conditions. Perry Village County Highway, Wyoming County, N. Y. Imported stone, delivery at middle of road—coal trestle available for unloading—no dead haul to road. Road 16 feet wide throughout.

Railroad at Station 60, Station 0 + 00 = beginning of contract
106 + 23 = end of contract

For ease of computation, say stone runs 10 yd. to mile.

Station 0 + 00 to 60

1.1 miles average 0.55 miles 0.55 miles $\times$ 11 yd. = 6.05 yd. miles

Station 60 + 00 to 106 + 23

0.87 miles average 0.44 miles 0.44 miles $\times$ 8.7 yd. = 3.83 yd. miles

Total yd. 19.7 9.88 yd. miles Total

$$\frac{9.88 \text{ yd. miles}}{19.7 \text{ yd.}} = 0.50 \text{ miles average haul}$$

Completion of Perry Village Estimate.

Stone from Rock Glen Quarries	Stone	$0.65	per ton f.o.b.
Cu. yd. = 2400 lb.	Freight	0.40	" " "
	Sub-base Stone	0.50	" " "

	Bottom		Top	Screenings	Sub-base
Stone	.78		.78	.78	.60
Unloading	.15		.15	.15	.15
Average haul ½ mi. at 0.35	.175		.175	.175	.175
Manipulation	.30		.25	.20	.20
				1.305	
Consolidation (plus ⅛)	.468		.451	.4 + ⅕	.22
				.5220	
Filler (½ cu. yd. sand at $1.00)	.50	Screenings	.522	Sand	.50
Profit (20%)	.474		.465		.369
Freight (40 + 0.08 + 0.16)	.64	(40+.08+ .16+192)	.832	(40+08 +.096)	.576
6% interest on freight to cover demurrage, etc.	.038		.05		.034
Manipulation of Bituminous Material			.60		
	$3.525		$4.275		$2.824
	Use $3.55		Use $4.30		Use $2.80

Case II

The Walker-Lake Ontario Road, Monroe County, N. Y. Road extends from Station 0 + 00 to Station 197 + 45.
Local stone—mostly fences. Because of location of stone as determined by engineer's inspection, it was determined to make three set-ups of crusher, at Station 40, 104 + 50 and at Station 157.

The hauls from stone piles to these crushing points were figured in the regular manner. From the crusher to road, the hauls were arranged,

From Station 40 — haul stone	0 + 00 to	77 + 00
" " 104 + 50 haul stone	77 + 00 "	130 + 00
" " 157 " "	130 + 00 "	197 + 45

Care was taken to see that enough stone was available near each crushing point to furnish macadam between stations supplied from that set-up.

The widths of road were as follows:

0 + 00 to 40 + 00 — 12′ wide
40 + 00 " 66 + 60 — 16′ wide
66 + 60 " 129 + 50 — 14′ "
129 + 50 " 197 + 45 — 12′ "

Use 10 yd. per mile for 12′ road
proportionally 11.7 yd. mile for 14′ road
" 13.3 " " " 16′ "

Haul on road from Station 40 + 00

12′ wide 0 + 00 to 40 + 00
0.76 miles average .38 .38 miles × 7.6 yds. = 2.89 yd. miles
16′ wide 40 + 00 to 66 + 60
.50 miles average .25 .25 miles × 6.6 yds. = 1.65 yd. miles
14′ wide 66 + 60 to 77 + 00
.20 miles average .1
plus dead haul .5
.6 .6 miles × 2.3 yds. = 1.38
16.5 5.92 yd. miles

Haul on road from Station 104 + 50

14′ wide Station 77 + 00 to 129 + 50 (say 130)
77 + 00 to 104 + 50
.52 miles average .26 .26 miles × 6.1 yds. = 1.59 yd. miles
104 + 50 to 130
.48 miles average .24 .24 miles × 5.6 yds. = 1.34 yd. miles
11.7 yds. 2.93 yd. miles

Haul on road from Station 157

12′ wide Station 129 + 50 (say 130) to 197 + 45
130 to 157
.51 miles average .26 .26 miles × 5.1 yds. = 1.33 yd. miles
157 to 197 + 45
.76 miles average .38 .38 miles × 7.6 yds. = 2.89 yd. miles
12.7 yds. 4.22 yd. miles

Average haul for entire road

From Station	40	16.5 yd.	5.92 yd. miles
" "	104 + 50	11.7 "	2.93 " "
" "	157	12.7 "	4.22 " "
		40.9	13.07

13.07 ÷ 40.9 = 0.32 miles
say 0.3 miles average haul

Sub-base Bottom Course

Stone	$ 0.15
Sledging, blasting, and sorting 30% of stone at 0.35 per yd.	0.105
Loading into wagons	0.15
Haul to crusher at Stations 40, 104 + 50 and 157. One mile at 0.35	0.35
Haul on road 0.3 mile at 0.35	0.105
Manipulation	0.20
Consolidation (plus ⅕)	0.212
Filler (½ cu. yd. sand at 0.80)	0.40
Profit (20%)	0.334
	$2.006

Use $2.00

Local Stone Top Course—Bituminous Binder

	Top Course	Screenings
Stone	0.15	0.15
Sledging, blasting, and sorting 60% of stone at 0.35	0.21	0.21
Loading into wagons	0.15	0.15
Haul to Crusher at Stations 40, 104 + 50 and 157. 1.1 miles at 0.35	0.385	0.385
Crushing	0.35	0.35
Haul on road 0.30 miles at 0.35	0.105	0.105
Manipulation	0.20	0.20
Consolidation (plus ⅓)	0.517	1.55
		× 0.4
Filler (0.4 cu. yd. of screenings)	0.620	0.620
Profit (20%)	0.537	
Manipulation Bituminous Material	0.60	
	$3.824	

Use $3.85

Case III

The Obi-Cuba Highway, #965, Allegany County, N. Y. 9.93 miles long.

From a field inspection of this road, it was found that stone was available at both ends of road, but not in the middle. An ample

supply of good gravel was found in the middle section, and it was determined to build a concrete base with bituminous top, this type of road being the only one which could be built using local material. The hauls and freight charges on imported material would make the cost prohibitive.

The road was divided into three sections as follows:

Station 0 + 00 to 330	local	field stone	concrete
Station 330 + 00 " 460	"	gravel	"
Station 460 + 00 " 524 + 14	"	quarry stone	"

Haul on stone 0 + 00 to 330. Crusher at 146, 220, and 285. These crusher set-ups were determined upon more by reason of nearness of stone supply and grade of haul than to equalize the hauling distance. The haul to the crusher was figured for the separate sources of supply and found to average 1½ miles.

Haul from crusher on road, Station 146 *to Station* 0 + 00

(12′ wide use 10 yd. per mile) 2.76 miles, average 1.38 miles.

Station 146 to 170	1.38 miles	×	27.6 yd.	=	38.09 yd. mile
0.5 miles, average 0.25 miles	0.25 "	×	5 "	=	1.25 " "
Station 220 to 170					
1.0 miles, average 0.5 miles	0.5 "	×	10 "	=	5.0 " "
Station 220 to 245					
0.5 miles, average .25 miles	0.25 "	×	5 "	=	1.25 " "
Station 285 to 245					
0.8 miles, average 0.4 miles	.4 "	×	8 "	=	3.2 " "
Station 285 to 330					
0.86 miles, average 0.43 miles	0.43 "	×	8.6 "	=	3.7 " "
Total for 1st section			64.2 yd.		52.49 yd. mi.

52.49 ÷ 64.2 = 0.82 mile, average haul for 1st section.

Haul from gravel pit to road. Station 330 *to* 460.

Bank station 385 at side of road—no dead haul great enough to be figured.

Station 385 to 330.
1.1 miles, average haul 0.55 miles 0.55 miles × 11 yd. = 6.05 yd. mi.
Station 385 to 460
1.4 miles average haul 0.7 miles 0.7 " ×14 " =9.8 " "

Total 25 yd. 15.85 yd. mi.

15.85 ÷ 25 = 0.63 miles Say 0.65 average haul

Haul from quarry in Village of Cuba ¾ mile from end of road.

Station 460 to 524 + 14
Station 460 " 500 14′ wide (use 11.7 yd. per mile)
Station 500 " 524 + 14 16′ wide (use 13.3 yd. per mile)
Station 460 to 500

0.8 miles, average	0.4 mi.
Station 524 + 14 to 500 dead haul	0.5 "
Quarry to 524 + 14 " "	0.75 "
	1.65 "

1.65 miles × 9.36 yd. = 15.44 yd. mi.

Station 500 to 524 + 14
0.5 miles, average haul 0.25 mile
Quarry to 524+14 dead haul .75 mi. 1 mile × 6.67 yd. = 6.67 yd.mi.

1.00 mi. Total 16.03 22.11 " "

22.11 ÷ 16.03 = 1.38 Say 1.4 miles average haul

Haul on Sand *Pits at Stations 26 and 385*

Station 26 to 0+00
0.5 miles, average 0.25 mi. 0.25 miles × 5 yd. = 1.25 yd. mi.
Station 26 to 330
5.76 miles, average 2.88 mi. 2.88 " × 57.6 " = 165.89 " "
Station 385 to 330
1.04 miles, average 0.52 mi. 0.52 " × 10.4 " = 5.4 " "
Station 385 to 460
1.4 miles, average 0.7 mi. 0.7 " × 14.0 " = 9.8 " "
Station 460 to 500
0.8 miles, average 0.4 mi.
385 to 460 dead haul 1.4 mi.

Total 1.8 " 1.8 " × 9.36 " = 16.8 " "

Station 500 to 524 + 14
0.5 miles, average 0.25 mi.
460 to 500 dead haul 0.8 mi.
385 to 460 " " 1.4 mi.

Total 2.45 mi. 2.45 " × 6.65 yd. = 16.3 " "

103.01 215.44

215.44 ÷ 103.01 = 2.1 miles average haul.

Haul on Cement

Cement delivered at Cuba and Portville.

Station 0+00 to 160 Say 10 bbl. to mile
3 miles, average 1.5 mi. 7.5 miles × 30 bbl. = 225 bbl. mi.
dead haul, Portville 6.0 mi.

to 0+00 7.5 mi.

Station 160 to 460
5.68 miles, average 2.84 mi.
460 to 524+14 dead 1.3 mi.
Penn. R.R. to 524+14 0.2 mi.

4.34 mi.
4.34 mi. × 56.8 bbl. = 246.5 bbl. mi.

Station 460 to 500
0.8 miles, average 0.4 mi.
500 to 524 + 14 dead 0.5 mi.
Penn. R.R. to 524+14 0.2 mi.

1.1 mi.
1.1 mi. × 9.36 bbl. = 10.3 bbl. mi.

Station 500 to 524+14			
0.5 average	0.25 mi.		
Penn. R.R. to 524+14	0.2 mi.	.45 mi.×6.65 bbl.	=3.0 bbl. mi.
	0.45	102.81	484.8 bbl. mi.

484.8 ÷ 102.81 = 4.7 miles, average haul.

Having the haul figured for stone, gravel, cement, and sand, it was decided to obtain a composite price for the aggregate of the concrete instead of presenting an estimate with three prices for concrete foundation. This was done as follows:

Field Stone.

Stone	$0.10 yd. royalty	
Blasting	0.35 "	
Loading	0.15 "	
Haul to crusher 1.5 @ 40c.	0.60 "	40c. yd. mile used as haul
[1]Crushing	0.30 "	was off steep hills and
Haul to road 0.8 mi. @ 35c.	0.28 "	hard grades
	$1.78 yd.	

Gravel.

Gravel (royalty)	$0.50
Stripping	0.05
Loading (by hand)	0.15
Haul to Station 385, 0.1 mile @ 35c	0.03
Haul on road, 0.65 miles @ 35c.	0.23
	$0.96

Stone at Cuba Quarry.

This stone bought from quarry owner at flat rate of 75c. in bins:

Stone	$0.75	
Haul 1.3 @ 35c.	0.455	
	$1.205	Say $1.21

Sta. 0+00 to 330=6.25 miles @ 10	yd.=62.5×$1.78=			$111.25
330 " 460=2.46 " " 10	" =24.6× 0.96=			23.62
460 " 500=0.8 " " 11.7	" = 9.36×1.21=			11.33
500 to 524+14=0.5 " " 13.3	" = 6.65×1.21=			8.05
	103.11			$154.25

$154.25 ÷ 103.11 = $1.49 composite price

Sand

Sand (screened)	$1.00 yd. royalty	
Loading	0.10 "	
Haul to road 0.1 @ 40c.	0.04 "	40c. used because of steep
Haul on road 2.1 miles @ 35c	0.735	hard grade
	$1.875	Say $1.88

[1] This item is higher than noted in the previously given cost data, as this estimate is made according to the N. Y. S. method, which does not consider interest and depreciation as a separate item.

Cement

Delivered at Cuba or Portville	$1.05 per bbl.
Haul 0.188 tons × 4.7 miles × 0.29 per ton mile	0.25 " "
	$1.30

Concrete.—Inasmuch as gravel must be screened and sharp sand supplied, the proportions for stone concrete, ratio 1—2½—5, were used in place of standard gravel proportions. This is Fuller's rule for proportions of cement, stone, etc., for one cubic yard of concrete. A table of these ratios for different mixtures is found on page 623.

Stone	$1.49	×	0.92	=	$1.3708
Sand	1.88	×	0.46	=	0.8648
Cement	1.30	×	1.21	=	1.573
					$3.8086
Mixing					$0.40
Spreading					0.20
Profit 20%					0.8817
					$5.2903

Say $5.30 per cu. yd.

NOTE.—This method of estimating does not consider depreciation directly. See other method of estimating in the standard estimate forms.

The method of estimating the top course for a Concrete Bituminous Top road does not vary from an ordinary bituminous top course, except that under the present New York State specifications the course is figured for loose measure. Therefore the items for consolidation and filler would be omitted.

Brick Cost Data on Country Roads.—The cost of brick pavements on country roads differs somewhat from similar work on city streets. There is not much data available for this class of work, but through the courtesy of Mr. Wm. C. Perkins, First Assistant Engineer, New York State Department of Highways, the author is able to give some unusually reliable data obtained from fifteen miles of brick paving averaging 14 ft. wide, built near Buffalo, N. Y., in 1910. Mr. Perkins' method of estimating, as given on page 651, assumes that 20% profit on both materials and labor will take care of the plant and payroll charges and give a reasonable profit. The method of estimating is different from that given on macadam roads. His results are good.

Excavation.—Where brick pavement is built on an ordinary unimproved country road, the excavation is of the same class and will cost the same as given for macadam roads.

Where pavements are built over macadam roads and the old surface must be cut into two or three inches and reshaped, the excavation is much more expensive. For this class of work see page 658 (scarifying and reshaping).

Labor Manipulation for Different Items of Brick Pavement Laid During 1910, in the Buffalo Residency.—These items figured from force accounts kept by the different engineers in charge of roads.

Labor averaged $0.175 per hour.

Concrete Base, 5″ thick (exclusive of edging).

Machine-mixing, laying same in place, including labor of tamping, etc.

Road No. 2–R, Buffalo-Hamburg...	$0.0853 per sq. yd.	
Road No. 128, Buffalo-Aurora.....	0.0991 " " "	(gravel concrete)
Road No. 863, Blasdell Village.....	0.1228 " " "	
Road No. 87, Main Street, Sec. 2.	0.1129 " " "	(3″ base)
Road No. 862, Hamburg Village...	0.0655 " " "	(28′ and 30′ wide)

The excessive cost on Blasdell Village due to a poor concrete mixer (gasoline) which was constantly breaking down.

On Main Street, Sec. 2, poor organization and too high priced men; also, lack of water, causing delays.

On Hamburg Village low price due to width of base 28′ and 30′, allowing work to progress faster.

On Road No. 69, Main Street, Sec. 1, edging and base were laid in one operation; gasoline mixer; plenty of water; cement, $1.12; sand $1.40; labor, $1.90 per day; stone, $1.12 per cu. yd.; base 3″ thick; 8″ edgings; cost in place, including edging $4.696 per cu. yd., or $0.506 per sq. yd., or $0.886 per lin. ft. of road.

Assumption.—If we assume $0.09 per sq. yd. as an average cost for 16′ road (exclusive of edging) the manipulation would be $0.648 per cu. yd.

If we assume $0.0655 per sq. yd. for street work (Hamburg Village) the manipulation would be $0.472 per cu. yd.

Concrete Edging. 8″ thick.

Hand-mixed; placing same, including erecting of forms, and removing same; tamping, placing steel, and all labor necessary.

Road No. 2–R, Buffalo-Hamburg,	$0.0730	per lin. ft. of edging
	0.0821	" sq. yd. of pavement (Road 16′ wide)
Road No. 128, Buffalo-Aurora ..	0.0555	" lin. ft. of 5″ edging
	0.0713	" sq. yd. pavement (Road 14′ wide)
Road No. 863, Blasdell Village ...	0.0826	" lin. ft. edging
	0.0929	" sq. yd. pavement (Road 16′ wide)
Road No. 87, Main Street, Sec. 2.	0.0748	" lin. ft. edging
	0.0842	" sq. yd. pavement (Road 16′ wide)

On Road No. 862, Hamburg Village, concrete curb 6″ top, 10″ bottom, 15″ deep; hand-mixed, exposed curbing, all labor, including erection and removal of forms, $0.1294 per lin. ft.

Assumption.—If we assume \$0.082 per sq. yd. of paving as cost of edging and \$0.09 per sq. yd. cost of base, the total cost per sq. yd., 16′ road (including edging) would be \$0.172 per sq. yd., or the manipulation would be \$1.238 per cu. yd.

If we assume \$0.073 per lin. ft. of 8″ edging 10½″ deep, the manipulation would be \$3.379 per cu. yd. of the edging in place. (This high cost due to forms, etc., and the small amount of concrete per lin. ft.)

Sand Cushion.—Spreading sand, rolling, and making bed ready for work.

Road No. 2–R,	Buffalo-Hamburg,	\$0.0102	per sq. yd.
Road No. 128,	Buffalo-Aurora,	0.0082	" " "
Road No. 863,	Blasdell Village,	0.0187	" " "
Road No. 87,	Main St., Sec. 2,	0.0151	" " "
Road No. 862,	Hamburg Village,	0.0160	" " " (28′ and 30′ wide)

On Main Street, Sec. 1, Road No. 69; sand, \$1.40; labor, \$1.90; cost per sq. yd. 2″ thick, \$0.0838, including material.

Assumption.—From the above I would assume \$0.013 per sq. yd. as cost of preparing sand cushion.

Brick Pavement.—Laying brick, including all labor of handling from the piles, removing all culls, and the rolling of the brick.

Road No. 2–R,	Buffalo-Hamburg,	\$0.0611	per sq. yd.
Road No. 128,	Buffalo-Aurora,	0.0544	" " "
Road No. 863,	Blasdell Village,	0.0969	" " "
Road No. 87,	Main St., Sec. 2,	0.0965	" " "
Road No. 862,	Hamburg Village,	0.0700	" " " (28′ and 30′
Road No. 69,	Main St., Sec. 1,	0.0983	" " " wide)

Assumption.—I consider Blasdell and Main Street, Sec. 1 and Sec. 2, too high and the engineer claims that the force was cut up and wasted time.

I would assume \$0.070 per sq. yd. as cost of laying brick, etc.

Grouting.—Necessary grouting to obtain flush joints, scoop method, including the placing of the protecting sand covering.

Road No. 2–R,	Buffalo-Hamburg,	\$0.0219	per sq. yd.
Road No. 128,	Buffalo-Aurora,	0.0211	" " "
Road No. 863,	Blasdell Village,	0.0322	" " "
Road No. 87,	Main St., Sec. 2,	0.0321	" " "
Road No. 69,	Main St., Sec. 1,	0.0285	" " "
Road No. 862,	Hamburg Village,	0.0273	" " " (28′ and 30′ wide)

On Main St., Sec. 1, Road No. 69; sand, \$1.40; cement, \$1.12; labor, \$1.90; actual cost \$0.0848 per sq. yd., including materials.

Assumption.—From the above I would assume \$0.028 per sq. yd., as the cost of applying grout.

Expansion Joints.—Removing strips, cleaning joints, and pouring tar.

Road No. 2–R, Buffalo-Hamburg,	$0.0067 per lin. ft. of joint 0.0076 " sq. yd. pavement (Road 16′ wide)
Road No. 128, Buffalo-Aurora,	$0.0057 per lin. ft. of joint 0.0073 " sq. yd. pavement (Road 14′ wide)
Road No. 863, Blasdell Village,	$0.0115 per lin. ft. of joint 0.0129 " sq. yd. pavement (Road 16′ wide)

On Main Street, Sec. 1, Road No. 69, the expansion joints cost $0.0296 per lin. ft., or $0.033 per sq. yd. (Road 16′ wide), including material, labor, etc.

Assumption.—From the above I would assume $0.0075 per sq. yd. as the cost of expansion joints.

Unloading.—Data for unloading not reliable.

Road No. 2–R Buffalo-Hamburg,	$0.014 per sq. yd.
Road No. 863, Hamburg Village,	Contract taken for $1.50 per 1000 brick; unloaded, haul ½ mile, and pile; this would be $0.06 per sq. yd.
Road No. 69, Main St., Sec. 1...	$0.019 per sq. yd.

Assumption.—I would assume $0.028 per sq. yd. as on and off.

Hauling.—No reliable data.

If we allow 600 brick per load, $5 per day for teams, 10 loads per day, haul 1 mile costs $0.034 per sq. yd.

Summary, Labor Cost of Brick Pavement.

MANIPULATION OF CONCRETE

Pavement 16′ wide; edging 8″ × 10½″.

*Concrete base..........	$0.09 per sq. yd....	$0.648 per cu. yd.
" edge.......	0.082 " " "...	3.378 " " "
Concrete base and edging	$0.172 " " "...	1.238 " " "

BRICK WORK LABOR

Preparing sand cushion................	$0.0130 per sq. yd.
Laying brick........................	0.0700 " " "
Grouting...........................	0.0280 " " "
Expansion joints....................	0.0075 " " "
On and off.........................	0.0280 " " "
Haul one mile.......................	0.0340 " " "
Cost of labor..................	$0.1805 " " "

Useful Data for Brick Roads.—

6″ × 10½″ edging per lin. ft. of edging........	0.016203 cu. yd.
8″ × 10½″ " " " " " "	0.021605 " "
5″ × 16′ concrete foundation per lin. ft. 16′ road.	0.24691 " "
2″ sand cushion loose per sq. yd..............	0.0555 " "

1 barrel of cement will grout 36 sq. yd. of pavement.

1 barrel of paving pitch will fill 130 lin. ft. of joints 1″ wide.

* Recent cost data indicates that $0.35 per cu. yd. is ample.

Amount of Grout Required for Stone Block Paving.—For blocks similar to Medina sandstone blocks, running about 26 to the sq. yd., Gillette states that 0.6 cu. ft. of joint filler are required per sq. yd. of pavement with joints averaging ½″ wide. Second quality blocks with wider joints require proportionally more.

STANDARD ESTIMATE, BRICK SURFACING, EXCLUSIVE OF FOUNDATION

Materials.

	Per Sq. Yd.
Cost of brick, f.o.b. unloading point	$
" " sand for sand cushion, on job	
" " " " grout, on job	
" " cement for grout, on job	
" " paving pitch for expansion joints, on job	

Labor and Teaming.

Unloading brick and piling along road	$0.035
Hauling brick per mile	0.040
Preparing sand cushion	0.020
Laying brick	0.070
Grouting	0.028
Expansion joints	0.007
Total	$ —
Add 20% profit	—
Estimate	$ —

SAMPLE—Standard Estimate, Brick Pavement—Wm. C. Perkins

Brick: $22.50 per 1000 f.o.b. cars at Road siding, bricks lay 40 to the sq. yd.

Labor, $0.175 per hour, 10 hours.
Sand, 1.00 per cu. yd. on cars at siding.
Stone, 1.25 per cu. yd. on cars at siding.
Cement, 1.30 per bbl. delivered on work.

Sand:

f.o.b. cars	$1.00
Unloading	0.15
Haul 1 mile @ $0.30	0.30
Cost cu. yd. sand	$1.45

Stone:

f.o.b. cars	$1.25
Unloading	0.15
Haul 1 mile @ $0.30	0.30
Cost cu. yd. stone	$1.70

Concrete: 1 – 2½ – 5.

Use any standard mixing tables, stone 1″ and under, dust screened out.

Cement, 1.19 bbl. ...	×	$1.30	=	$1.55
Sand, 0.46 cu. yd. ...	×	1.45	=	0.67
Stone, 0.91 " " ...	×	1.70	=	1.55
*Manipulation			=	0.50
				$4.27
20% profit				0.85
Total				$5.12

The manipulation is based on machine-mixing and is for base alone laid 5″ thick. The concrete edging is estimated separately and runs from $0.13 to $0.15 per lin. ft.

Material per Square Yard

Brick f.o.b. cars	$0.900	
Sand cushion and cover	0.080	
Grout (sand and cement)	0.042	
Material expansion joint	0.008	
		$1.030

Labor per Square Yard

Unloading and piling	$0.035	
Haul 1 mile	0.040	
Laying and rolling	0.070	
Making sand cushion	0.020	
Grouting	0.028	
Expansion joints	0.007	
Culling, replacing, etc	0.005	0.205
		$1.235
20% profit		0.247
Total		$1.482

Therefore, standard 16′ road is estimated to cost, per square yard (exclusive of edging):

Concrete base	$0.711	
Brick	1.482	
Total	$2.193	per sq. yd.
Say,	$2.20	per sq. yd.

*Recent cost data indicates that $0.35 is ample with labor at $0.175 per hour.

In the above estimate I have allowed 20% profit on material and freight. I do this so as to cover all interest charges, incidentals, contingencies, etc. I consider this one of the fairest ways to take care of all general expenses.

MAINTENANCE AND REPAIR COSTS

Cold Oiling.—The following data is furnished by Mr. Frank Bristow, Supt. of Repairs, Division No. 5, New York State Department of Highways. The work was done in 1910. Labor averaged $0.20 per hour; teams, $0.50 per hour.

Oiling. Actual Cost Data.—No. 6 stock or 65% asphaltic base oils applied cold by Studebaker Oiler upon macadam road which had been swept by horse sweeper, oil being broomed by hand where necessary and then covered by a thin coat of dustless screenings, or gravel, spread by hand.

The labor costs include pumping oil from the car tank, hauling same to road, applying same, sweeping road and spreading screenings; also, demurrage on cars and moving tools and repairs, but not cost of the plant.

Table 64

			Average cost of materials		Average Quantities of Materials Used		Average Cost	
County	No. Jobs Average	Average Haul, Miles	Oil per Gal. on siding	Cover per Cu. Yd. Along Road	Gallons per Sq. Yd.	C. Y. Cover per Sq. Yd.	Labor per Sq. Yd.	Total Labor and Material per Sq. Yd.
Orleans.	7	2.48	$0.0435	$1.82	0.42	0.016	$0.013	$0.057
Niagara.	4	2.24	0.0425	1.57	0.43	0.016	0.014	0.057
Erie.	12	2.00	0.0437	1.88	0.34	0.012	0.007	0.045
Erie	3	4.43	0.0455	1.83	0.42	0.015	0.019	0.066

Other information would show that cost per mile to sweep average road is $8.33; cost per gallon applying oil $0.0075; cost all labor sweeping, hauling, applying oil and cover about $0.25 per gal. used.

TABLE 64A
DIVISION 7 N. Y. S. DEPT. HIGHWAYS
H. G. HOTCHKISS SUPT. MAINTENANCE
Cost Data for Oiling, Surface Treatment 1915

Miles	No. Sq. Yds.	Kind Bit. Mat.	Gals. per Sq. Yd.	No. Tons of Cover per Mile	Total Cost per Sq. Yd.	Total Av. Cost per Sq. Yd.	Cost per Mile 16' Surface
20.54	158144	C. O.	0.25	62	0.0344		
23.63	188208	C. O.	0.25	41	0.0250		
17.75	146734	C. O.	0.24	37	0.0237		
19.94	172775	C. O.	0.19	43	0.0189	0.026	244.06
21.47	200995	C. O.	0.19	59	0.0264		
16.22	199925	C. O.	0.28	74	0.0287		
22.51	188601	L. C. O.	0.20	31	0.0195	0.0183	171.78
41.09	382330	L. C. O.	0.20	27	0.0177		
15.44	126657	H. C. T.	0.25	40	0.0323	0.0330	309.77
13.42	126056	H. C. T.	0.25	40	0.0337		
17.19	143846	L. C T.	0.25	47	0.0319	0.0319	299.45

TABLE 64 B
DIVISION 7 N. Y. S. DEPT. HIGHWAYS
Cost Data Repainting and Rebuilding Guard Rail 1914

No. Lin. Ft. Painted One Coat	Cost per Lin. Ft.	No. Lin. Ft. Painted Two Coats	Cost per Lin. Ft.
15325	$0.0212	26428	$0.0425
79925	0.0233	8433	0.0360
17486	0.0251	12824	0.0352
42027	0.0264	13160	0.0442
Rebuilding Wooden Guard Rail		**Rebuilding Concrete Guard Rail**	
No. Lin. Ft.	**Cost per Ft.**	**No. Lin. Ft.**	**Cost per Ft.**
160	0.219	100	$0.896
554	0.189	335	0.764
360	0.200		
272	0.141		

COST DATA SURFACE TREATMENT

It will be noted in the following table that the tendency of surface oiling practice is to each year reduce the amount of oil and cover used. This is in line with the data set forth in the chapter on Maintenance.

Hot Tar Flush Coats.—The cost of applying hot tar flush coats by hand is practically the same as given for applying Bituminous Binder penetration method.

The writer has no reliable data on the cost of machine application.

Calcium Chloride.—The cost of applying calcium chloride as a temporary dust layer on ten miles of road in Monroe County, N. Y., as given by Mr. Frank Bristow, First Assistant Engineer, New York State Department of Highways, is as follows:

The material was applied by an ordinary agricultural drill. The force used was, 1 horse and driver, $0.30 per hour; 1 helper, $0.20 per hour. No preliminary work of sweeping was done; the material was spread on the middle 12 feet of macadam, using approximately 0.75 lb. to the sq. yd., the average speed being 0.5 miles, or 3500 sq. yd., per day, at a cost of $0.0015 per sq. yd.

Cost of calcium chloride at plant......	$13.00	net ton
Freight............................	1.60	per "
Unloading from cars, approximately...	0.15	" "
Hauling three miles, "	0.90	" "
Total, delivered on road..........	$15.65	" "
Total per sq. yd. delivered on road....	0.0059	
Labor of spreading.................	0.0015	
Total per sq. yd. in place.......	$0.0074	
Total per mile 12′ wide, approximately..............		$52.00

Cost of Applying Calcium Chloride

Road No. 5507 Scottsville—Canawagus. Season 1915. W. G. Harger, Eng. in charge.

15 tons were applied at the rate of 1½ lb. per sq. yd. on a 16′ road for $22.00 or at the rate of $1.50 per ton.

Force used, 1 team hauling agricultural plaster spreader. 2 laborers helping driver. Calcium Chloride in metal drums had been previously distributed along the road.

Wages: Team, $5.00 per day; Laborers, $2.00 per day.

Recapping.—The cost of recapping with any style of macadam is practically the same as original construction for that style of work except the item of scarifying and reshaping the old road.

Scarifying.—The cost of scarifying, as given by Mr. E. A. Bonney on the Erie County repair work for the season of 1907, is as follows:

(*Continued page* 658.)

Cost Data Surface Treatment with Oil and Tar

New York State Department of Highways Division No. 7

Cold Application

Contract Work

Year	Miles	Total Number Gallons Used	Total Average Cost per Mile	Total Average Cost per Sq. Yd.	Cover Lb. per Sq. Yd.	Cover Cost per Sq. Yd.	Bit. Mat. Gal. per Sq. Yd.
1916	148.96	52,717 Tar 35,389 L.H.O. 159,228 L.C.O.	$221.77	$0.0252	8	$0.0065	0.19
1915	229.21	236,827 C.O. 114,186 L.C.O. 99,140 Tar	217.37	0.025	10	0.0101	0.25
1914	188.96	225,533 C.O. 201,583 Tar	404.36	0.047	18	0.0218	0.26

Departmental Force Account

Year	Miles	Total Number Gallons Used	Total Average Cost per Mile	Total Average Cost per Sq. Yd.	Cover Lb. per Sq. Yd.	Cover Cost per Sq. Yd.	Bit. Mat. Gal. per Sq. Yd.
1916	47.21	84,294 Tar 7,164 L.C.O.	$192.84	$0.022	8	$0.0039	0.22
1915	57.10	23,358 C.O. 17,081 L.C.O. 54,099 Tar	284.79	0.034	12	0.0113	0.23
1914	53.73	112,690 Tar 29,796 C.O.	409.32	0.048	18	0.0220	0.28
1913	13.49	33,955 Tar	601.12	0.072	28	0.0244	0.30

	Contract Work							
Hot Application	1915	7.37	17,560 Tar	$521.67	$0.074	28	$0.0263	0.29
	1914	13.87	{ 15,362 Tar 24,720 H.O.	817.80	0.102	61	0.0538	0.30
	Departmental Force Account							
	1915	4.51	13,131 H.O.	$812.94	$0.114	39	$0.0444	0.41
	1914	1.00	4,693 H.O.	1,413.21	0.150	58	0.0710	0.50
	1913	8.75	31,119 H.O.	1,222.18	0.138	51	0.0529	0.40
	Contract Work							
No Cover	1915	1.96	3,674 L.C.O.	$112.64	$0.012			0.20
	1914	0.50	1,173 C.O.	224.00	0.024			0.25
	1913	2.26	4,243 C.O.	150.45	0.016			0.20

Cost of Bituminous Material per Gallon							Cost of Labor per Hour		
Year	Tar, Cold Application	Tar, Hot Application	Light Hot Oil 65–75% Asph.	Light Cold Oil 40–55% Asph.	Cold Oil 50–65% Asph.	Hot Oil 85–95% Asph.	Year	Labor Cents	Teams Cents
1916	$0.0592	$	$0.057	$0.051	$	$	1916	20–30	50–62½
1915	0.058–0.066	0.1025		0.031	0.032	0.059	1915	15–25	50–62½
1914	0.066–0.096	0.093			0.034–0.076	0.0777	1914	15–25	50–62½
1913	0.075					0.1125	1913	15–25	50–62½

COST DATA ON RESHAPING ROAD

Work was done on Main Street Road, No. 69, Erie County, N. Y., between July 15 and Sept. 13, 1907.

The road had been built as a waterbound macadam. It was worn out, particularly in the center. There were few ruts, but the road was nearly level; in some stretches the center was lower than the sides. It was proposed to reshape the road and to lay a new top course treated with tarvia.

The work of reshaping was done by loosening the old surface with spiked wheels of roller; this separated the crust into chunks of various sizes which were broken up by men with picks. The stone was then raked from the sides to the center, brought to the required crown, and rolled ready for the new course of stone.

The cost of the complete operation included the number of men picking and the rollerman's salary.

Labor	$0.175 per hour
Rollerman	0.300 " "

The roller was rented at a flat rate of $5.00 per day, and a portion of the time it was used on other parts of the work. This cost plus the coal and oil is not included.

The data was compiled daily, and as the work was performed practically every working day between the dates named an average of the square yard price should be nearly correct. The highest cost on any one day was $0.06 per sq. yd., the lowest cost $0.016, and the general average $0.03 per sq. yd.

[1]Through the courtesy of Mr. Halbert P. Gillette, author of "Handbook of Cost Data," we are able to publish the following:

Cost of Resurfacing old Limestone Macadam.—"In Engineering News, June 6, 1901, I gave the following data to show that the intermittent method of repairing macadam is the most economic. The data were taken from my timebooks and can be relied upon as being well within the probable cost of similar work done by contract under a good foreman. It will be noted that the cost of operating the roller is estimated at $10.00 per day. This includes interest and depreciation as well as fuel and engineman's wages.

"The road was worn unevenly, but as it still had sufficient metal left, very little new metal was added.

"The roller used was a 12-ton Buffalo Pitts, provided with steel picks on the rear wheels. It required eighty hours of rolling with the picks in to break up the crust of a surface 19,400 sq. yd. in area, 240 sq. yd. being loosened per hour. The crust was exceedingly hard, and, at times, the picks rode the surface without sinking in, so that a lighter roller would probably have been far less efficient. In fact, a ten-ton roller had been used a few years previous for the same purpose at more than double the expense per square yard, I am told. The picks simply open up cracks in the crust to a

[1] Gillette's Handbook of Cost Data, Myron C. Clark Publishing Company, edition of 1907, page 147. Pages 288 and 289, edition of 1910, in slightly different form.

depth of about four inches, and it is necessary to follow the roller with a gang of laborers using hand picks to complete the loosening process. The labor of loosening and spreading anew the metal was 1.880 man-hours, or a trifle more than 10 sq. yd., per man-hour. About 60% of this time was spent in picking and 40% in respreading with shovels and potato hooks.

"After the material had been respread, the short section was drenched with a sprinkling cart, water being put on in such abundance that when the roller came upon the metal the screenings which had settled at the bottom in the spreading process were floated up into the interstices. The roller and sprinkling cart were engaged only 63 hours in this process, 300 sq. yd. being rolled per hour; an exceptionally fast rate. The rapidity of rolling was due to four factors; 1. The great abundance of water used, the water being a very short haul. 2. The unyielding foundation (telford) beneath. 3. The abundance of screenings and fine dust, the road not having been swept for some time. 4. The great weight of the roller, which was run at a high rate of speed. I am not prepared to say that longer rolling would not have secured a harder surface, but I doubt very much whether it would. The metal, I should add, was hard limestone. Summing up, we have the cost of resurfacing the road per square yard to have been as follows:

	Cents per sq. yd.
Picking with roller at $1 per hour	$0.40
Picking by hand labor at $0.20 per hour	1.20
Respreading by hand labor at $0.20 per hour	0.80
Rolling with roller at $1 per hour	0.33
Sprinkling with cart at $0.40 per hour	0.13
Foreman, 143 hours at $0.30 for 19,400 sq. yd.	0.44
Total	3.30

"At this rate a macadam road sixteen feet wide can be resurfaced for a little more than $300 per mile. The frequency with which such resurfacing is necessary will, of course, depend upon several factors, chief of which are the amount of traffic and the quality of the road metal. I should say that five years would not be far from the average for a country road built of hard limestone. Unless the road has had an excess of metal used in its construction, new metal should be added at the time of resurfacing to replace that worn out.

"I am unable to see how any system of continuous repair with its puttering work here and there can be as economical as work done in the manner above described. I would not be understood, however, as favoring an entire neglect of the road between repair periods. At times of heavy rains and snows, ditches and culverts need attention and there should be some one whose duty it is to look after such matters. What I do question is the economy of having a man continuously at work putting in patches upon the road."

[1]NEW YORK STATE PATROL MAINTENANCE, 1910

The standard Patrol distance is five miles.

The standard Patrol distance, brick roads, is twelve miles.

Patrolman's wages $78 per month, including horse and cart. Patrol is operated eight and one-half months in a year.

The cost of this system of maintenance per mile for 1910 was, approximately, $250 exclusive of administration charges.

Patrolman's wages	$125.00
Materials	125.00
	$250.00

These costs do not include surface treatments. Such a treatment of a road every two years would amount to about $375 a mile per year on waterbound roads.

Automobile Truck Repair System.—The tendency on minor repair maintenance work seems to be toward lengthening the patrol distance; confining the duties of the patrolman to cleaning culverts and ditches, trimming shoulders, and reporting the necessity of minor repairs. It is believed that these repairs can be handled more economically from a central point by the use of an automobile truck specially equipped for such work and which can operate within a radius of 20 to 30 miles. Special trucks have been devised with facilities for heating and applying bituminous materials as well as carrying materials.

Conclusion.—In conclusion the author desires to again call the attention of the reader to the fact that while cost data is valuable it must be used with discretion and not figured too closely.

[1] Data obtained from Mr. Frank Bristow, Supt. of Repairs, N. Y. S. Dept. of Highways.

Table showing Character of Maintenance and Renewal Expenditure for 1914, over 500 Miles of Road

Div. No. 7

New York State Commission of Highways

Perry Filkins
Div. Engr.

Maintenance Department Report 1914

H. G. Hotchkiss, Jr.
Act. Supt. of Maint.

County	Miles	Resurfacing		Oiling		Patrol	Maint. Mat.	Extra Labor	Guard Rail	Miscel.	Eng. and Insp.	Total
		Miles	Cost	Miles	Cost							
Genesee	31.90	3.00	$9470.50	24.74	$6419.63	$2574.00	$310.86	$910.44	$451.55	$161.67	$2072.13	$22370.78
Ontario	100.99	5.59	40068.03	52.38	19399.66	7311.00	4167.60	7921.50	1713.78	286.96	3930.98	84799.51
Orleans	58.14	3.47	13482.82	36.02	15796.64	4629.00	2337.01	1388.86	460.34	94.26	4537.10	42726.03
Livingston	82.05			41 19	16392.56	6753.00	2044.05	557.83	1441.77	334.00	3550.66	31073.87
Monroe	220.19	4.75	68062.19	100.36	50682.88	14331.00	13317.54	9683.57	3702.02	980.57	9534.42	170300.19
Wyoming	21.36			4.00	2423.60	1866.00	811.77	1573.51	581.85	70.73	1358.40	8685.86
Total	514.63	16.81	$131083.54	258.69	$111114.07	$37464.00	$22988.83	$22035 71	$8351.31	$1934.19	$24983.69	$359956.24

Average Cost per Mile Oiling $429.52 Engineering and Inspection 6.94%
" " " " Resurfacing 7797.95
The Items of Maint. Mat. and Extra Labor Monroe Co. Includes 5.75 Miles Calcium Chloride Ave. Cost per Mile $185.23
Average Cost per Mile Patrol 73.00
No. Ft. Guard Rail Painted One Coat 154763 Average Cost per Foot .0240
" " " " " Two Coats 60845 " " " " .0403
" " Wooden Guard Rail Rebuilt 1426 " " " " .19
" " Concrete " " " 2196 " " " " .85

CHAPTER XV

NOTES ON CONSTRUCTION

No matter how well a road is designed, unless the constructing engineer uses good judgment, and the inspection is conscientious and intelligent, the results will not be satisfactory. This chapter emphasizes the importance of the different stages of the work and gives a few suggestions as to the manner of meeting common difficulties.

Staking out for Construction.—The construction survey picks up the center line shown on the plans and by means of offset stakes driven to a certain elevation marks the position and ele-

Staking Out								Notes				
Sta	Offsets		Cut or Fill		Levels				Grade	Grade Rod Reading	Rod Reading on Stakes	
	L	R	L	R	B S	F S	Elev	H. I.	Elev.		L.	R.
BM S							526.42					
10	25	23	F0.5	F1.0	4.17			530.59	524.2	6.4	6.9	7.4
+50	25	22	F0.5	F.5				"	524.6	6.0	6.5	7.5
11	24	25	F0.5	F1.5				"	525.0	5.6	6.1	7.1
+50	21	26	C0.5	F1.0				"	525.4	5.2	4.7	6.2
12	22	25	C0.5	F1.5				"	525.8	4.8	4.3	6.3
+50	23	24	C1.0	F2.0				"	526.2	4.4	3.4	6.4
13	24	24	Gr	Gr				"	526.6	4.0	4.0	4.0
+50	25	23	Gr	F0.5				"	527.0	3.6	3.6	4.1
14	30	17	Gr	C0.5		3.20	527.39	"	527.8	2.8	2.8	2.3
+50	25	23	Gr	C1.0	7.41			534.80	528.6	6.2	6.2	5.2
15	25	23	C0.5	F1.5				"	529.4	5.4	4.9	6.9
+50	25	23	F1.0	F1.0				"	530.2	4.6	5.6	5.6
16	25	23	Gr	C1.0				"	531.0	3.8	3.8	2.8
+50	25	23	F1.5	C1.0				"	531.8	3.0	4.5	2.0
17	24	24	F1.5	Gr.				"	532.6	2.2	3.7	2.2
+50	18	28	F1.0	F5.0				"	533.4	1.4	2.4	6.4
								"				

FIG. 137.

vation of the road conveniently for building. Any arrangement of stakes that shows the position of the proposed center line and the elevation of the proposed grade is satisfactory. These stakes may be set on one or both sides of the road at intervals of 50 or 100 feet. The offsets to the center line may be marked to the nearest one-tenth foot, or the stakes may be so set that the offset is an even foot, and they may be driven so that the elevation of the proposed grade is above or below them an even foot, one-half foot, or an odd tenth. A satisfactory method in general use in western

New York is to set the construction stakes on both sides every 50 feet, with an even foot offset and driven to such elevation that they are either an even foot or one-half foot above or below grade. Such stakes can be readily explained to the ordinary grading foreman so that he has no difficulty in working from them without the assistance of an inspector. The 50-foot interval is convenient for fine grading, as the lines can be stretched this distance with no apparent sag, while if a 100-foot interval is used the sag is objectionable. With stakes on both sides of the road the elevation of the proposed grade can be readily transferred to the center by stretching a line between them and measuring down or up the required amount. This is a much simpler and more accurate method than transferring by straight-edge where two or three lengths of straight-edge must be used from the stake to the center.

The left stake marked C 4.0′ offset 28.0′ means that the crown grade of the finished road is 4.0 feet below the top of this stake and

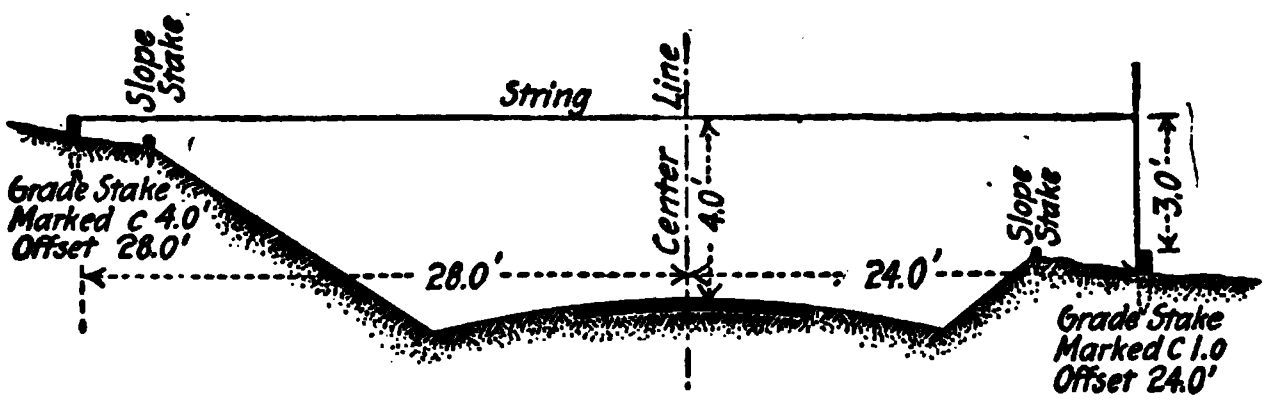


FIG. 138.—Showing suggested method of staking out.

that the proposed center line of macadam is 28.0′ from the face of the stake.

To transfer the proposed grade to the center by the string method. Fasten chalk line to top of left stake; measure up 3.0′ above top of right stake and draw line taut at this elevation. The string is level and 4.0′ above crown grade. Pull as tight as possible, allow about ½″ for sag and measure down 3′ 11½″ for finished grade.

Cost of Staking Out.—The speed and cost of staking at 50-foot intervals will, of course, vary with the experience of the men and the character of the road. A party of four men should pick up the proposed center line and set offset stakes on both sides at a speed of 1.5 to 2 miles a day; a party of three men should grade these stakes at a speed of 1.0 to 2.0 miles a day, and the cost of staking out for construction, including livery and board, would be from $20 to $30 per mile.

It is common for new men to spend an unnecessary amount of time in setting the grade stakes. They will often attempt to have the elevation of the grade stakes correct to within 0.01 foot. For all practical purposes, for work of this character, stakes correct to within 0.1 foot in elevation and 0.1 foot in alignment are satisfactory. Curb stakes for village work, however, should be carefully set to within 0.02 foot in elevation and line.

CONSTRUCTION

Rough Grading.—By rough grading is meant all of the work preliminary to the finished shaping, and includes moving practically all the dirt that is to be handled. It is particularly important to supervise this stage of construction, as it is here that the constructing engineer regulates the placing of the best material in the center (under the metalling) and the poorer materials on the sides.

In order to grade economically, the contractor and inspector should each be furnished with lists similar to those given below, showing, in a convenient form, the amount of excavation station by station and within what bounds it is to be placed.

Cuts.—For cuts over 3 feet deep slope stakes are placed and care taken that the slopes are properly carried down. If excavated

Excavation Summary

Sta. to Sta.		Exc.	Emb.	Waste	Borrow
123	134	476	375		
134	140	286	340		
140	157	642	662		185
157	178	766	629		
178	179	231		231	
179	186	288	244		

Detail Quantities

Sta. to Sta.		Exc	Emb.
123	123+50	575	225
123+50	124	150	900
124	124+50	—	1450
124+50	125	150	900
125	125+50	320	200
125+50	126	170	600
126	126+50	30	825
126+50	127	30	650
127	127+50	260	410
127+50	128	350	250
128	128+50	635	180
128+50	129	635	75

Lists

Remarks

Quantities in cu. yds.

Haul from Sta. 179 to 150

Quantities in cu. ft.

FIG. 139.

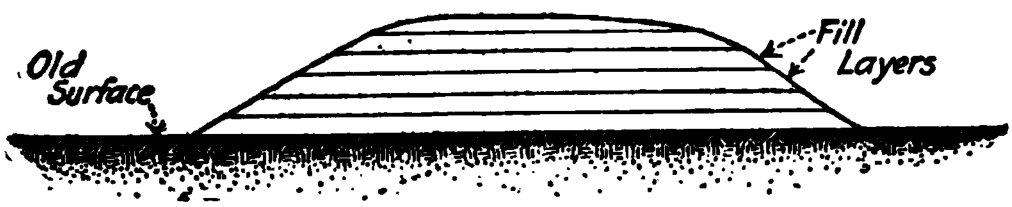
beyond the finished lines it is practically impossible to make a back-fill that will hold and the resulting irregularities are unsightly.

Fills.—For fills slope stakes are set in the same manner as for cuts.[1] The earth should be deposited in thin layers, six to eight inches deep, extending from slope to slope, and each layer well compacted either with a roller or by driving over it with wagons in the process of building Where the old surface has a steep slope it must be plowed to give a good bond with the new fill and prevent slide.

[1] Slope stakes can be located directly from the templet Cross Section which is a much easier method than the railroad practice of rod and level computation.

It is bad practice to build the center of the fill and then shovel loose material off of the edge to widen the slopes, as this loose side-fill is not compacted and under the action of frost will nearly always slough away from the harder central portion.

To get the full benefit of the teaming in compacting the dirt, a deep fill should be started at a point nearest the cut from which the material is hauled and each load driven over the loose layer. In this way nearly every fill can be better compacted than by the use of a roller alone. For long fills where there is considerable teaming over each layer a roller is not usually needed.



Wet clay or heavy loam should never be placed in the bottom of a fill, as it dries slowly when not in contact with the air and keeps the fill "spongy." The writer has seen cases where fills not over 3 feet deep have remained soft for two months where wet material had been used and it was finally necessary to remove it.

Transferring Grade from Stakes.—A handy level for transferring the grade from stakes to the center of the road is shown below. If well made it will transfer the grade elevation 50 feet with an error of less than 3 inches, which is close enough for this stage of the construction:

FIG. 140.

Ditches.—The ditches *must always* be dug out enough to protect the center grading before the fine grading (stone trench) is completed, and it is usually cheaper for the contractor, as well as better for the road, to dig them out before the fine grading begins.

Regulation of Material in Fills.—In fills, particularly shallow ones, the road can be greatly improved by a judicious selection of available materials. Material taken from two nearby cuts, or at different depths in the same cut, will often vary in character and the most experienced man on the job should indicate which materials to use in the center of the fill, under the metalling, and which on the sides. The soils in the order of value for fills are gravel, coarse sand, loam, and clay. For shallow fills on a good foundation clay should not be used under the stone, as mentioned on page 151, and a good material must be overhauled or borrowed. It is better to avoid overhaul if possible, as it is an item liable to be disputed as to the amount. Where it is necessary, a good practical method of determining the amount of the small quantities of earth usually needed is to keep track of the number of wagon loads overhauled from station to station.

Sod may be used in the sides of the fill, but should be kept at least eleven feet off center. It should NEVER be used as a shoulder close to the stone or in the center of the fill under the metalling.

The author wishes to emphasize the importance of this regulation of material. At present the inspection of rough grading is often confined to keeping the sod from the center fill, and the center fill is made of the dirt just as it happens along. As a result, the sub-grade will vary greatly in character and if a uniform depth of stone is used over this "spotty" fill the results are often not satisfactory, while if the depth of stone is varied to meet the sub-grade conditions an unnecessary amount of stone is used. In cases where there is no choice of earth materials the stone depth must be made thick enough to meet the requirements of the grade.

FINE GRADING FOR STONE TRENCH

The fine grading includes the shaping and consolidation of the stone trench.

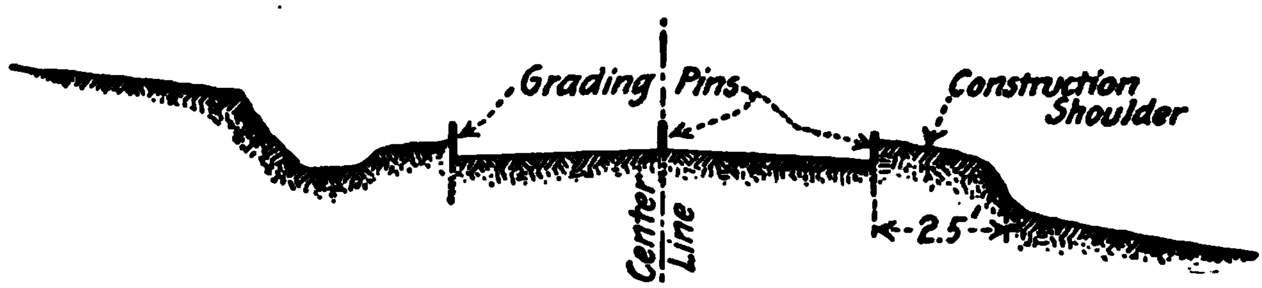


FIG. 141.—Showing 3 lines of grading pins.

The construction shoulder must be at least 2.5′ wide and well consolidated in order to hold the stone solidly during rolling. This must be watched continually by the inspector as it is a point often slighted.

Shaping the Grade.—A simple guide for shaping the grade is shown in the accompanying sketch and consists of three strings (center and sides) stretched between pins driven at least every 50 feet and preferably every 25 feet. The pins should not be placed at intervals of more than 50 feet as this will cause objectionable sag in the lines and the grade will be undulating. The grade elevation is transferred and the lines carefully set at their proper elevation by means of a straight-edge, level and rod, or by stretching a line between grade stakes on opposite sides of the road as previously described. The string level recommended for rough grading can not be used, as it is not sufficiently accurate.

The general level of the finished consolidated grade should be correct to within 1 inch. This leeway of 1 inch from the figured grade makes it possible to get satisfactory results without wasting time on finical work and does not appreciably affect the total amount of excavation, as the errors tend to balance. There should, however, be no short, small irregularities of grade noticeable to the eye. Continuous inspection on shaping the grade is not necessary.

Consolidating the Grade.—Most soils when slightly moist will consolidate readily if thoroughly rolled. Clay, heavy loams, or excessively fine sandy loams (quicksand) will not pack when wet. Continued rolling is injurious for these soils in this condition, as they will "work" under the roller. If they occur only in small pockets they can be removed and replaced with good material; if in stretches of any length the grade must dry out before placing the stone. Under drains are constructed at this time, where necessary, and the surface ditches are cleaned out and made effective. Where a hard shower has softened the surface only of a previously consolidated grade of this kind and the contractor wishes to lay stone, the surface can be hardened by spreading a thin layer of gravel or waste No. 2 stone and rolling it into the earth. This will help in preventing the stone teams from cutting up the grade.

Gravels and finely pulverized clay, or clay loams (deep dust), will not consolidate when dry; such material must be thoroughly sprinkled to get a compact grade. It is not, however, customary to sprinkle coarse gravels, even if slightly loose, as no objectionable results follows from placing stone on such a grade; deep clay or loam dust is objectionable and must be sprinkled.

Coarse sand makes an ideal foundation but is hard to keep in shape while placing the first layer of stone. In some cases sprinkling will harden it sufficiently; in others a layer of fine loam has been spread over the sand and flushed in with satisfactory results. Sometimes where loam is not available a cheap cheese-cloth has been spread over the top of shifting sand to prevent the stone from punching in too much under the roller. The author has never encountered any coarse sand that could not be successfully treated by sprinkling and covering with 1 inch or 2 inches of No. 2 stone; the blanket of No. 2 stone prevents the sand from squeezing up into the loose bottom stone and spreading the fragments.

While coarse sand makes a good foundation, a fine sand or sandy loam approaching quicksand is very treacherous; it is difficult to judge the degree of fineness at which a sand becomes treacherous, particularly when it is dry. A laboratory method is given on page 150, but a good practical method in the field is to saturate the material thoroughly with water; a satisfactory sand becomes more compact while an exceedingly fine sand gets "quaky."

DETERMINATION OF STONE DEPTHS AND CONSTRUCTION OF SUB-BASE

Practically the only engineering problem that the constructing engineer has to solve is that of foundations. It is recognized by most designers and estimators that it is impossible from even a careful preliminary examination of the soil to specify exactly the amounts and depths of foundation stone. To meet this an extra quantity of sub-base or bottom stone is allowed the constructor, to be used as he sees fit. During the progress of the rough and fine grading the exact limits of the different kinds of sub-grade

soil are determined and the stone depths varied according to his judgment. (See page 152.) Men that really understand this part of the work are hard to get, as it is only from extended experience and intelligent study of their own failures and successes that a sound judgment is developed. A good constructing engineer is much more difficult to find at present than a good technical designer.

Where sub-base is used the sub-grade is dug out to the required extra depth and rolled if it is in such shape that it will not "work." Peat, muck, wet fine sand, or wet clay can not be rolled until the sub-base is placed and filled. Where it is possible, such soils should be drained and allowed to dry before placing the base, but is often not feasible to dry them enough to allow rolling, even though underdrainage is put in, which partially hardens them and successfully protects the road after the stone has been placed. This is particularly true on flats where it is hard to get an outlet for a drain or in the fine sands on which an under drain has little effect on account of the capillary action of the material. Where a soft sub-grade of this kind is encountered, a stony gravel makes the best sub-base, as it contains no voids between the larger fragments and when rolled the soft underlying material can not squeeze up through the course. In case boulder or quarry stone base is used on a soft grade, it is necessary to lay them in close contact by hand and then fill the voids completely with gravel or No. 2 stone *before* rolling; otherwise the sub-grade material would squeeze up between the stones, separating them and partially destroying the efficiency of the base.

In the Spring and Fall of the year it is common to find good material so saturated from long-continued rains that it acts badly under the roller and instead of waiting for the grade to dry out, when the normal thickness of stone would be sufficient, sub-base is often put in either to help the contractor so that he will not be delayed or because the engineer is misled as to the character of the material. This results in a waste of money. On the other hand, clay, when thoroughly dry, is hard and firm, which often influences a new man to omit sub-base where it will surely be needed.

The use of sub-base should not depend too much on the action of the grade under the roller unless the degree of saturation of the material is considered, although it serves as a guide in locating doubtful spots. The final determination should depend on test pits, which develop the character of the underlying material.

The sub-base is constructed, as explained, in the chapter on Foundations, either of gravel, boulder or quarry stone. The depth is gauged by lines. The ratio of loose to rolled depth is given on page 591.

Continuous inspection is not needed on sub-base; the depth of grading is checked before the stone is placed and the width, depth, and workmanship can be readily determined after the base is completed, and by an occasional inspection during the progress of the work.

Bottom Stone.—The earth sub-grade must be firm and compact before the stone is spread. Bottom stone must NEVER be laid on a soft grade. One of the most common slips of inspection is to allow this to be done and the result is a "punky" bottom course that is never up to standard. The distributing power of this course depends largely on the stone fragments being firmly interlocked; if the stone is placed on a soft grade and rolled, the earth will squeeze up between the fragments and separate them.

The depth of the loose stone is gauged by the lines or cubical wooden blocks placed on the sub-grade. Blocks are more convenient than lines except over sub-base of stone fills, where lines must be used to get a spread true to shape and grade. The ratio of loose to rolled depths is given on page 591.

The loose stone is rolled until the stones are solidly interlocked and there is no movement under the roller. A thin layer of satisfactory filler (see materials page 240) is spread over the top, rolled and broomed in; the process is repeated until the stone is thoroughly filled. Continuous inspection on bottom course is not necessary. The widths and depths can be readily checked by occasional inspection. The two points to be carefully watched during construction are: 1. That the grade is firm; 2. that the loose fragments are thoroughly rolled *before* the filler is applied.

It is desirable to complete the bottom course well in advance of the top, in which case the contractor can work to advantage after rains, and the course will be better compacted by subjecting it to some traffic action.

Where local stone is crushed on the job and the stone used ranges in size from 1 in. to tailings, care must be used in spreading that the sizes are well mixed, as pockets of fine or coarse stone are objectionable. The simplest method of mixing is to run the No. 3 and No. 4 and tailings into one bin at the crusher; if they are separated they can be well mixed by loading one end of the wagons with the No. 3 and the other end with No. 4 and when dumped on the grade they will run together. When difficulty is experienced with these methods in obtaining a well-mixed stone spread the loose stone can be harrowed. Many specifications call for harrowing thoroughly where a large range of crushed stone size are allowed in one course. If possible, tailings should be used as sub-base. When used in the bottom course having a rolled depth of 4 or 5 inches they should be placed in the lower part of the course, but for a 3-inch depth they should be placed on top and broken with a knapping hammer into fragments of less than 3½ inches.

The filler should not be dumped directly on the stone unless absolutely necessary. Drawing the loads onto the unfilled stone loosens the course, and, also, at each pile of filler there is apt to be left an excess which is hard to clean off.

Table 65 gives the approximate amount of filler required per 100 feet, and the spacing of 1½-yard loads. The amount varies for the different materials used.

Grading and foundations have been treated at some length, as they are the most difficult parts of the construction.

TABLE 65. GIVING THE APPROXIMATE AMOUNT OF FILLER REQUIRED PER 100 FEET OF ROAD FOR CRUSHED STONE MACADAM BOTTOM COURSES OF DIFFERENT WIDTHS AND DEPTHS, USING 0.35 CUBIC YARDS OF FILLER PER CUBIC YARD OF ROLLED BOTTOM

Width of M'cadam	Rolled Depth of Bottom Course			
	3"	4"	5"	6"
10′	3.2 cu. yds.	4.3 cu. yds.	5.4 cu. yds.	6.6 cu. yds.
12′	3.8 " "	5.1 " "	6.5 " "	7.6 " "
14′	4.5 " "	6.0 " "	7.5 " "	9.0 " "
15′	4.9 " "	6.4 " "	8.0 " "	9.9 " "
16′	5.2 " "	6.9 " "	8.6 " "	10.4 " "
18′	5.9 " "	7.9 " "	9.7 " "	11.8 " "
20′	6.4 " "	8.6 " "	10.8 " "	12.8 " "
22′	7.0 " "	9.4 " "	11.8 " "	14.2 " "

TABLE 65A. GIVING THE APPROXIMATE SPACING OF 1.5 CUBIC YARD LOADS OF FILLER FOR THE WIDTHS AND DEPTHS SHOWN IN TABLE 65

Width of Macadam	Rolled Depth of Bottom Course			
	3"	4"	5"	6"
10′	46 feet	34 feet	27 feet	23 feet
12′	40 "	30 "	23 "	20 "
14′	33 "	25 "	20 "	17 "
15′	31 "	23 "	19 "	15 "
16′	29 "	22 "	17 "	13 "
18′	25 "	19 "	16 "	12 "
20′	23 "	18 "	13 "	11 "
22′	21 "	16 "	12 "	10 "

TOP COURSES

Waterbound Top.—Waterbound top is constructed in the same way as the bottom course except that stone dust is used for a filler and the course is puddled as has been described.

If the stone used is a local stone crushed on the job the output of the crusher must be carefully controlled, especially where selected boulders are used, as it is very important that the size and quality of such stone shall be uniform.

Imported stone can be inspected on the cars. Aside from this, comparatively little inspection is required except at the stage when the loose stone has been rolled and before the binder is spread. At this time the inspector should examine the rolled course very carefully to see that it is true to shape and has no short depressions or humps. The smooth riding quality of the road

depends on this inspection and too much care cannot be taken. This point is particularly emphasized, as many of the stone roads in New York State have been criticized as rough for automobile traffic. Any depressions are filled with stone of the same size as the body of the course and rolled, after which the course is again inspected and corrected until it is made true. The binder is then spread, broomed in dry, and puddled. In puddling use plenty of water and roll rapidly. If a pipe line and hose are used a pressure of 100 to 125 pounds at the pump should be maintained. The road can be conveniently puddled in stretches of 100 to 200 feet.

After the road has dried out and been opened to traffic, if raveling occurs it can usually be remedied by light sprinkling and rolling.

Where the top course is granite, gneiss, or trap, it is often necessary to use a certain percentage of limestone dust with the normal screenings. The limestone is more effective when spread last, filling the top voids of the course.

Bituminous Top. Penetration Method.—The same procedure applies to the quality, size, and laying of the stone for a bituminous as for waterbound top, and does not require continuous inspection.

Just before pouring the bitumen the course should be carefully examined and any pockets of fine stone, dirt, dirty or dusty stone removed, as fine stone or dirt prevents the penetration of the binder and the bitumen will not adhere properly to the stone unless it is clean and dry. The course is not rolled as firmly at this stage as for waterbound tops because excessive rolling tightens the stone too much and prevents the penetration of the bitumen. There should, however, be no creep in front of the roller. The bitumen is poured into the voids of this *clean, dry, partially* compacted course, usually by means of hand-sprinkling pots or hods. Pots having vertical slots are preferable to the fan-spout pots, as they give better penetration.

When hods or pots are used, however, the bitumen should be poured across the road instead of in a longitudinal direction as this prevents overlap and minimizes the difficulty of preventing humps or waves.

In placing the bitumen the following precautions must be observed: It must be hot enough to run freely; for each grade the temperature of applications is usually specified and it must *not* be overheated, for if charred it is useless. In applying, by whatever method, care must be taken not to overlap, as waves or humps will develop at these points. These defects do not appear for some time after the road is opened to travel, and an inexperienced inspector fails to realize the necessity of care in this particular. The stone must be clean and dry, and, in the writer's opinion, the air temperature should not be less than 50° F., as bitumen applied in cold weather is so chilled when it strikes the cold stone that an excessive amount is retained on the surface. As soon as the bitumen is applied a thin layer of No. 2 stone is spread over the surface and rolled lightly; continued rolling at this point is injurious, as freshly laid bituminous tops tend to shove under the roller and form waves. The road can be thoroughly

rolled and shaped to advantage only after the bitumen has had some time to harden. Good results have been obtained by rolling thoroughly the succeeding day after the binder is applied, unless in the meantime rain has saturated the course, in which case it must be allowed to dry before rolling.

The amount of bitumen spread per square yard is usually controlled by spreading a given number of pots or hods in a given length of the road. These units of length can readily be marked off by the inspector with a stick or tape. This method will be satisfactory if checked up twice a day by the number of barrels used. When the binder is heated in small kettles it will sometimes catch fire, but this is usually due to scale which has collected in the tank and if cleaned out it generally remedies the trouble.

Where bituminous materials are heated by steam it is often convenient to know the temperature of steam at different pressures; the following table is inserted for this purpose:

TABLE 66

Pressure Gauge Lbs. per Sq. In.	Temperature of Steam °F	Pressure Lbs. per Sq. In.	Temperature °F of steam	Pressure Lbs. per Sq. In.	Temperature °F of steam
[1] 15	213	100	328	200	382
20	228	120	341	220	390
40	267	140	353	240	397
60	293	160	363	260	404
80	312	180	373	280	411
100	328	200	382	300	417

[1] Fifteen pounds normal air pressure; to get ordinary steam gauge reading subtract 15 lbs. from the values given in this table.

HASSAM CONCRETE PAVEMENT

By E. E. Kidder

The principal mechanical difficulty in laying a Hassam pavement is in getting a proper penetration of the grout.

This requires stone free from small particles and a grout of the proper consistency.

Stone.—The stone should be sized 1½" to 3½" uniformly mixed. Any pockets of fine stone should be shoveled out or if they occur in small areas raked over till the fine goes to the bottom of the course.

The spreading is followed by rolling with a 10-ton road roller. Close attention should be given to obtaining as nearly a perfect surface as possible as it is practically impossible to add or deduct material once the stone is grouted.

Grout.—The grout should penetrate to the bottom but should not be so thin that separation occurs. The size of sand is important.

Coarse sand will not penetrate well. Sand passing a 10 mesh to the inch screen and containing much that is finer works well.

Manipulation.—Each morning the end of the previous day's work should be cut down vertically and square across the road, shoveled out and replaced with new stone. This insures a vertical joint. *Continuous Inspection is Necessary on both Stone and Grout.* The grout will float a few of the top stone out of place but the 5-ton tandem roller will smooth them down. The final finish is obtained by hand tamping and brooming the surface. The tamping is absolutely necessary to get the best results and it will be neglected unless insisted upon.

Shoulders.—It is desirable that the earth shoulders be left 1" higher than the finished pavement until the grouting is completed to prevent waste. During the rolling of the grout some water will flush to the surface and run to the edge; it should be let off by digging small trenches through the shoulder. The grading of the shoulders should be practically complete before laying stone in order that the Sand and Cement may be placed on one side of the road and the other shoulder may be used as a walk for the workmen and traffic. The gang organization is shown by a sketch (page 607, Cost Data).

FIRST CLASS CONCRETE PAVEMENTS

By F. W. Bristow

The sub-grade should be formed true to alignment, elevation and shape and consolidated well in advance of the mixing machine to permit the delivery of materials both on the sub-grade and shoulders.

The materials, stone or screened gravel, sand and cement should be distributed uniformly in the proper quantities to construct the pavement as planned. (For quality of materials see specifications. For amounts required see Cost Data.) The cement should be delivered on the road only as required and covers provided for its protection in case of storm.

Inspection of Manipulation.—A diagram showing a typical mixing gang organization is given in the chapter on Cost Data. Two inspectors are necessary to properly supervise the work. The inspection *must be continuous.* The inspector ahead of the mixer sees that the sub-grade is correct; that the edging forms are properly set; that the fine and coarse aggregate conforms to the requirements, and that the proper amount of materials are placed in each batch of concrete.

He also should keep a daily record of the amount of cement used, the amount of concrete laid and should figure the amount of cement per. cu. yd. of concrete as a check on his batch inspection. He should be careful to observe that no empty cement sacks from the previous days run are counted the second time.

The inspector back of the mixer first sees that the sub-grade is smoothed as the mixing machine moves ahead; that any muddy condition is remedied by removal and that a dry dusty sub-grade is

sprinkled to prevent rapid absorption of water from the concrete; that the concrete as delivered from the mixer has the proper consistency and is thoroughly mixed; that the transverse expansion joints are properly placed; that the striking of the concrete with the screed[1] or template is so done as to leave no projecting stone, or humps or hollows in the surface. Any surface irregularities must be immediately remedied and the mass restruck. The screeding is kept up closely to the mixer and is followed by the wood float finishers working from a bridge that spans the concrete.

In case surface brooming is required the inspector determines when it shall be done; the best time is just after the initial set starts. Long-handled steel brooms are used and the brooming is done lightly transversely to the road.

In hot weather the fresh concrete should be sprinkled to prevent sun checking. It is covered within 24 hours with a coat of earth 1" to 2" thick which is sprinkled and kept damp for 10 days when it

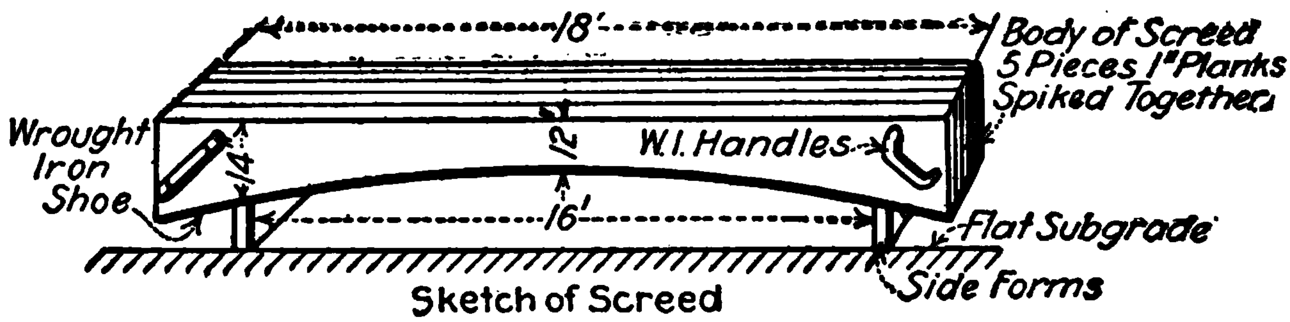


FIG. 142.

is removed. Traffic must be barricaded from the road for this time.

Before turning traffic on to the completed concrete the earth shoulders should be finished along the edge to prevent spauling.

Amount of Water.—Excess water must be guarded against as it weakens the concrete. A good practical rule is the use of about 5½ to 6 gal. of water per sack of cement, see Chapter on Materials on the Use of Water in Concrete, page 262.

SUGGESTED SPECIFICATIONS FOR ROLLER FINISH[2]

THE following is a suggested form of specifications for roller and belt finish: "as soon as possible after the concrete has been struck off, it shall be rolled with an approved metal roller, having a smooth, even surface, approximately six (6) feet in length, not less than eight (8) inches, nor more than twelve (12) inches in diameter, and weighing not more than one hundred (100) pounds. On pavements less than twenty (20) feet in width, the roller may be operated with a handle, which shall be at least two (2) feet longer than the width of the pavement, and all rolling shall be done from one side of the slab. On pavements twenty (20) feet and

[1] The screed should be two feet wider than the finished pavement as it progresses with a see saw movement rather than a direct full.

[2] Quoted from the "Concrete Highway Magazine," of March, 1918.

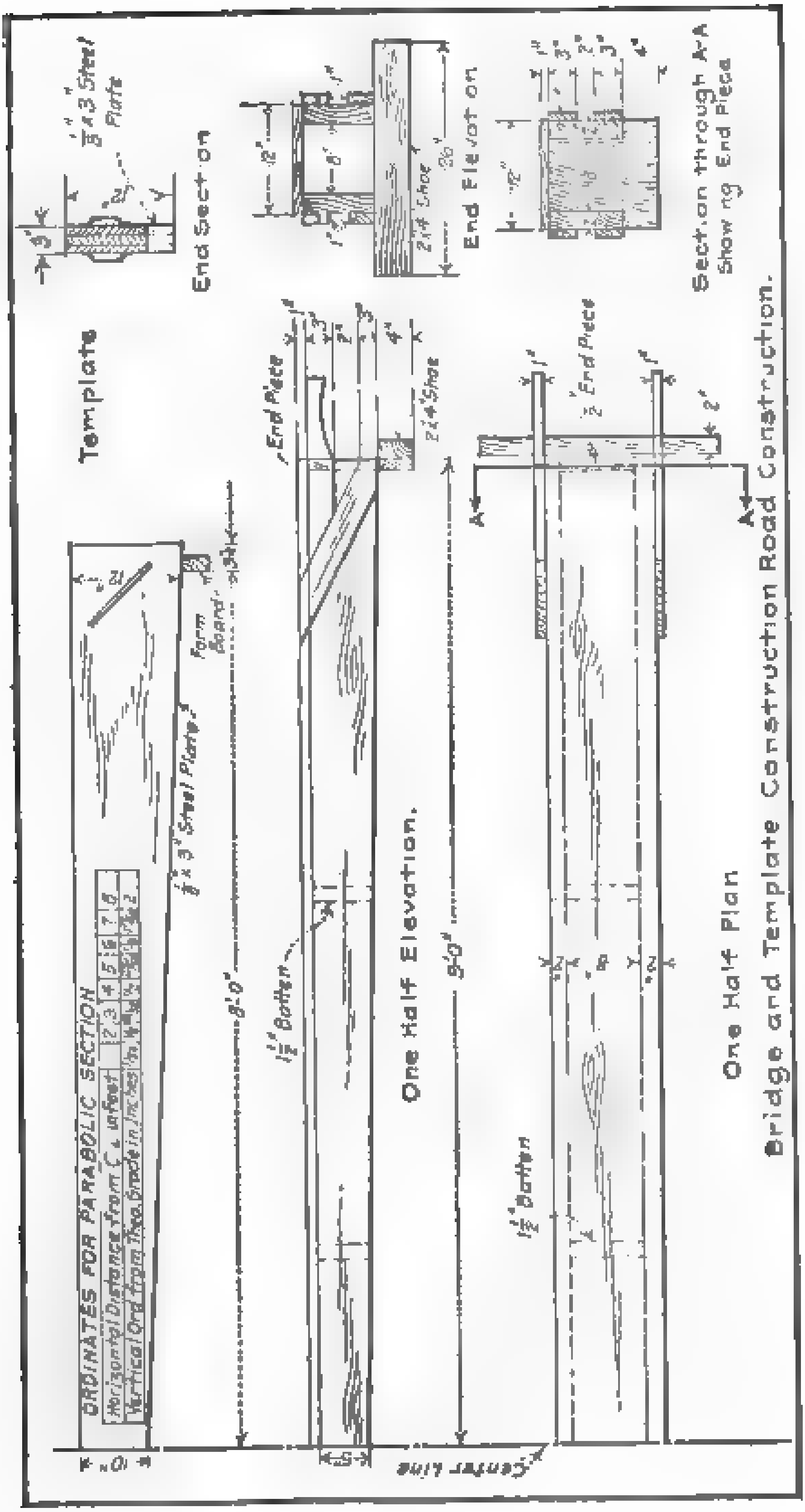

Template
End Section
End Elevation
Section through A-A Showing End Piece
ORDINATES FOR PARABOLIC SECTION
Form Board
End Piece
One Half Elevation.
One Half Plan
Center Line
Bridge and Template Construction Road Construction.

FIG. 143.

Area of Cross-Section, Cubic Yards,* Quantities of Materials Required per Linear Foot and Square Yards of Surface for Concrete Roads for Various Widths and Thicknesses Shown

* Based on 1 bbl. cement equal 4 cu. ft.· voids in stone, 45%. Factors used from Taylor and Thompson "Concrete, Plain and Reinforced."

Width, Ft.	Thickness Sides, In.	Thickness Center, In.	Thickness Average, In.	Area of Cross-Section, Sq. Ft.	Cu. Yd. Concrete per Linear Foot of Pavement	Sq. Yd. per Mile	Quantities per Linear Foot: Cement, Barrels 1:2:3	Cement, Barrels 1:1½:3	Sand, Cu. Yd. 1:2:3	Sand, Cu. Yd. 1:1½:3	Rock or Pebbles, Cu. Yd. 1:2:3	Rock or Pebbles, Cu. Yd. 1:1½:3
9	6	8	7.333	5.500	0.204	5,280	0.355	0.389	0.106	0.086	0.157	0.173
10	6	8	7.333	6.111	0.227	5,867	0.394	0.433	0.118	0.095	0.175	0.123
18	6	8	7.333	11.000	0.407	10,560	0.708	0.777	0.212	0.171	0.313	0.346
18	7	9	8.333	12.500	0.463	10,560	0.806	0.884	0.241	0.194	0.357	0.324
18	8	10	9.333	14.000	0.519	10,560	0.903	0.991	0.270	0.218	0.400	0.441
20	6	8	7.333	12.222	0.453	11,733	0.788	0.866	0.235	0.190	0.349	0.385
20	7	9	8.333	13.777	0.510	11,733	0.887	0.974	0.265	0.214	0.393	0.434
20	8	10	9.333	15.555	0.576	11,733	1.002	1.100	0.300	0.242	0.444	0.490
24	6	8	7.333	14.667	0.543	14,080	0.945	1.037	0.282	0.228	0.418	0.462
24	7	9	8.333	16.667	0.617	14,080	1.074	1.178	0.321	0.259	0.475	0.524
24	8	10	9.333	18.667	0.691	14,080	1.202	1.320	0.359	0.290	0.532	0.587
26	6	8½	7.667	16.611	0.615	15,253	1.070	1.175	0.320	0.258	0.474	0.523
26	7	9½	8.667	18.777	0.695	15,253	1.208	1.327	0.361	0.292	0.535	0.591
26	8	10½	9.667	20.944	0.776	15,253	1.350	1.482	0.404	0.326	0.598	0.660
27	6	9	8.000	18.000	0.667	15,840	1.161	1.274	0.347	0.280	0.514	0.567
27	8	11	10.000	22.500	0.833	15,840	1.449	1.591	0.433	0.350	0.641	0.708
30	6	9	8.000	20.000	0.741	17,600	1.289	1.415	0.385	0.311	0.571	0.630
30	8	11	10.000	25.000	0.926	17,600	1.611	1.769	0.482	0.389	0.713	0.787
36	6	9½	8.333	25.000	0.926	21,120	1.611	1.769	0.482	0.389	0.713	0.787
36	8	11½	10.333	31.000	1.148	21,120	1.998	2.193	0.597	0.482	0.884	0.976
40	6	10	8.667	28.888	1.070	23,467	1.862	2.044	0.556	0.449	0.824	0.910
40	8	12	10.667	35.555	1.317	23,467	2.292	2.515	0.685	0.553	1.014	1.119

Cement for 1 cu. yd. concrete: 1-1½-3 Mix.: 1.91 bbl.; 1-2-3 Mix.: 1.74 bbl.

Sand for 1 cu. yd. concrete: 1-1½-3 Mix.: 0.42 cu. yd.; 1-2-3 Mix.: 0.52 cu. yd.

Stone for 1 cu. yd. concrete: 1-1½-3 Mix.: 0.85 cu. yd.; 1-2-3 Mix.: 0.77 cu. yd.

Author's Note.—A well-graded aggregate 1 : 1½ : 3 mix will reduce the cement factor to about 1.80 bbls. per cu. yd.

more in width, the roller shall be provided with two (2) bails to which ropes shall be attached, and the roller pulled across the pavement. The roller shall be operated at such an angle with the center line of the pavement that it advances along the pavement about two (2) feet for each time across. The roller shall pass from one edge of the pavement to the other, care being taken not to run the roller over the side forms so that earth or other foreign material will adhere to it. After the roller has covered a given area in the manner described, the same area shall be similarly covered by the roller for not less than three times at intervals of fifteen to forty minutes, and as many times additional as may be necessary to remove excess water.

"After the rolling has been completed the pavement shall be finished by two applications of a belt made of canvas or rubber belting, not less than six (6) inches wide and not less than two (2) feet longer than the width of the pavement. The belt shall be applied with a combined cross-wise and longitudinal motion. For the first application vigorous strokes at least twelve (12) inches long shall be used, and the longitudinal movement of the belt along the pavement shall be very slight. The second application of the belt shall be immediately after the water glaze or sheen disappears, and the stroke of the belt shall be not more than four (4) inches, and the longitudinal movement shall be much greater than for the first belting."

Sheet Asphalt, Topeka Mix, Etc.—The important points in any form of a mixed Bituminous surface are a proper grading of the aggregate and care not to char the binder in mixing. The concrete base for asphalt pavements should have a rough finish.

Two inspectors are required; one at the plant and one where the asphalt is being laid. *Plant inspection should be continuous.* The plant inspector is responsible for the proper proportions of the different sizes of the aggregate and for the proper temperature of the mix. To insure the proper proportions he should test the measuring scales at short intervals and sift a sample of the dry mineral aggregate at least once a day. His most important duty is to prevent charring of the binder. It is not necessary to take the temperature of each batch as with a little experience any objectionable condition can be detected by the character of the smoke; a dense white smoke given off when mixing indicates a dangerously high temperature. When this is observed the batch should be tested with a thermometer and immediately rejected if over the specified temperature limit. (See specifications.) The temperature of the mineral aggregate will fluctuate very rapidly in the small plants generally used for road work and care should be observed in picking the plant inspector that he is a very conscientious man. He should also furnish the driver of each load of asphalt with a ticket giving the weight of the mix on that load.

The Inspector on the road records the temperature of the mix as received, the weight of each load and indicates to the spreaders the number of sq. yd. it should cover.

(The surface mix weights approx. 100 lb. per sq. yd. per inch of consolidated depth.)

He also should take a sample of the mix as delivered once a day and ship to the laboratory for check analysis.

The following sketches show a sample of a plant inspector's and road inspector's record book.

SEPT. 29, 1914. PLANT RECORD

Load Record				Bitumen Record	
Load	Time	Temperature of Mix.	Weight of Load	Time	Temperature
1	7.30	320° F.	5000 lbs.	7.00	310° F.
2	7.45	310	5000 "	8.00	345
3	7.55	300	6000 "	9.00	340
4	8.15	300	6000 "	10.00	310
5	8.25	290	5000 "	11.00	305
6 etc.	8.45	310	5000 "	12.00	320

TEST SAMPLE NO. 7. SEPT. 29, 1915. ROAD RECORD

Load No.	Time	Temperature of Mix.	Weight as per Ticket	No. Yds. Covered	Location on Road
1	8.00	310° F.	5000 lbs.	25	Sta. 10 + 30 to 10 + 42
2	8.20	300	5000 "	25	" 10 + 42 " 10 + 54
3	8.30	295	6000 "	30	" 10 + 54 " 10 + 69
4	8.45	295	6000 "	30	" 10 + 69 " 10 + 84
5 etc.	9.00	280	5000 "	25	" 10 + 84 " 10 + 96

Proportions of Mix.—The proportions of mix should be determined by the engineer by screen analysis of the different materials that the contractor proposes to use.

As an example assume that a mixture of cement, fine sand, coarse sand and buckwheat stone is proposed and it is desired to determine the relative amounts of the different materials to use in order to get the correct proportion of sizes specified.

For all ordinary purposes a size analysis can be safely made using the following screens: #200, #80, #40, #10, 1/4" and 1/2".

The materials are thoroughly dried and the percentages expressed by weight.

Fine Sand (Feeder Pit)

Passing # 200	5%
" # 80 retained on # 200	70%
" # 40 " " # 80	25%

GOOD QUALITY

Coarse Sand (Bauerman Pit)

Passing # 200	1%
" # 80 retained on #200	2%
" # 40 " " # 80	29%
" # 10 " " # 40	68%

Buckwheat Stone. (Commercial plant.)

Passing # 200		1%
" # 40 retained #200		2%
" # 10 " # 40		7%
" ¼" " # 10		60%
" ½" " ¼"		30%

The proportions can now be varied to produce practically any required mix.

Tabulation Showing Method of Determining the Number of Pounds of Each Material to be Used in a 100 lb. Batch to Produce a Required Mix.

Material	No. lbs.	Bitumen	#200	#40	#10	¼	½
Bitumen......	10	10	—	—	—	—	—
Cement.......	7	—	7	—	—	—	—
Fine Sand......	47	—	2.5	44.5	—	—	—
Coarse Sand ..	20	—	—	6.0	14.0	—	—
Buckwheat Stone......	16	—	—	—	1.0	9.6	5.4
Totals........	100	10	9.5	50.5	15.0	9.6	5.4

In this way the effect of varying any of the component parts of the mix can be readily seen and determined.

The total size of the batch is of course varied to suit the capacity of the plant.

The laboratory analysis of the daily sample taken on the road furnishes a check on the plant inspector.

Rollers.—The best results can be obtained by the use of two tandem rollers; a light roller not over 5 tons for first compression to anneal the surface while hot and a heavier 8 to 10 ton roller for final compression and cross-rolling. This is more important where the asphalt is laid on a macadam base than when laid on concrete.

BRICK ROADS

To cover the points of construction of brick roads we can not do better than to give "Instructions for Inspectors," by William C. Perkins, Resident Engineer, New York State Department of Highways. Mr. Perkins is well qualified to judge of this class of work.

Grading.—"Read your specifications carefully and follow them in every particular.

"Do not let the contractor dig beyond the back slopes of your ditches. Your ditches should be straight, no sudden jogs; back slopes all true; no rubbish deposited back of the ditches, and be sure that your ditches drain.

"Follow your cross-sections as closely as possible. Try to aid the contractor to take care of his dirt so that when the road is cleaned up there will not be a great amount of material to be moved.

"Never make a shovel fill over 6 inches without rolling it.

"In making a heavy fill with dump wagons begin to dump at the end toward your dirt supply. Have each pile of dump dirt spread thin and draw the next load over this, which will help to pack it. All should then be thoroughly rolled.

"Examine your sub-grade carefully, particularly when the roller is going over same, and if it waves or shakes under the roller, sub-base or drain should be put in, or the material dug out and the proper material put in. Do not make a fill with any old material found along the road. Use judgment in this particular.

"Clearing and grubbing does not mean the grubbing of sod. It means the cutting down of bushes, trees, etc. Remember that the life of your pavement is the condition of your sub-grade. The same should be inspected by the engineer in charge before any stone or concrete is placed.

"Grade the full width of your macadam or concrete. Never deposit stone in the rut. Keep your sub-base free of ruts.

"If your roller is not working on other work roll your sub-grade. You can not roll it too much.

"Do not shift center line or grades until you have reported the necessity for it to headquarters, and if absolutely necessary give an estimate of the increase or decrease in quantities that such change would make.

"Shoulders should not contain sod within 18 inches of the macadam.

"Back slope all ditches 1 on 1½. Be careful that your gutters are not too deep. Deep gutters where not necessary for drainage purposes make a road dangerous and must be avoided.

"In trimming shoulders and ditches a good inspector should be put on the work, and instructed to see that the contractor sets proper stakes. A stake should be set out from the edge of the macadam, and also one in the ditch, and should be set at least every 100 feet. The bottom of the ditch must be a true grade, no depression, and the ditch alignment must be good. These stakes can be easily set with a 16-foot level board. When approaching a culvert it is not necessary to deepen the gutters until you reach within 50 feet of same, when a straight grade can then be run to the invert.

"In all cases be sure your ditches will carry water, and, I repeat, be sure they are not ragged and the back slopes are well graded. In trimming shoulders be sure there is no ridge next to the macadam.

"In setting your stakes for the shoulder work use the ordinates and distances shown on the standard section.

"**Subgrade.** Be sure that your subgrade has been properly graded so as to obtain 5 inches of concrete. If the contractor builds the curb first, a templet should be run over the curbing and test made to be sure that you have the correct depth.

"**Concrete Edging.**—Stakes for concrete edging can be placed every 50 feet for line and grading, with the exception at change of grades and curves, where they should be placed every 25 feet.

"Be sure that your forms are properly set as to line and grade.

"With stakes 50 feet apart be careful that there is no sag in the line when the forms are set.

"If edging is set first it is better that the concrete be hand-mixed, as a machine turns out too large a quantity and can not be placed in the proper time.

"See that your forms are wet before the concrete is placed, and if steel forms are used they should be oiled.

"Have a careful inspector on the mixing of the concrete for the edging and watch the mix.

"Keep track of the number of bags of cement used and see that the proper proportion of cement to the lineal foot of edging is obtained.

"Edging 6" × 10½" will use 1 bag in 12.95 feet

"Edging 8" × 10½" will use 1 bag in 9.73 feet

"Mixture, 1 – 2½ – 5.

"Make the mixture rather wet and spade the same thoroughly, using a hoe straightened and punched full of holes, or some similar instrument, so as to get a good face next to the forms.

"If you find you can not get a good top surface keep the edging a couple of inches low, and about every third batch mix a batch of fine material and bring the edging up to the proper height, thoroughly working the same in.

"Do not get a plaster effect, but get a good top surface.

"Round both edges with a rounding tool, making the inner edge of a smaller radius than the outer edge.

"When the forms are taken down all spots which are honey-combed, or rough, should be floated at once with cement. A rough edging should not be left on any road.

"Have the contractor back up the edging as soon as possible.

"In warm weather the edging should be kept wet for, at least, twenty-four hours. Have the contractor use care in delivering materials after the edging is built so that the edges of same are not broken by wagons, etc.

"A good edging is often ruined by carelessness on the part of the contractor.

"**Concrete Base.**—Before laying base be sure that the foundation is in proper shape and of a proper depth.

"Lay the concrete rather wet and drag same with a heavy templet. Have men back of the templet with tamping irons or blocks, tamping the concrete. This is important if you wish to get a smooth surface, and you must insist that the concrete be well tamped.

"Be sure that you keep track of your bags, and, also, that the machine is working properly.

"For a 16-ft. road 11¾ bags will lay 10 ft. concrete base, mixture 1–2½–5.

"After the day's run examine your base, and if there are any spots which are porous, grout same and check up your bags at the end of each day.

"If the weather is very hot the base should be kept wet for twenty-four hours.

"**Sand Cushion.**—Sand for this cushion should be absolutely free of stones, and you must insist that the contractor screen same, if stones are in the sand delivered. No excuses will be taken for stones or pebbles in the cushion. Spread sand for a sufficient depth, then roll same with a small roller; then drag, roll again, and then drag with templet.

"This should be sufficient to give a firm cushion.

"The smoothness of the pavement depends on the proper form of the cushion.

"**Cement Sand Cushion.**—Use same order of manipulation as for sand cushion except that after culling and rolling the brick the pavement must be sprinkled thoroughly to wet the cushion and set it up before grouting.

"**Brick.**—Great care must be used in obtaining proper brick surface.

"Be sure that your strips on the side expansion joints are in when the contractor starts to lay brick.

"Allow no pinning in at the ends under 2½ inches.

"Be sure that the expansion joint is not ragged. It must be uniform in width, otherwise you will have transverse cracks.

"All bricks should be laid with lugs in the same direction. This is a point that the bricklayers very often do not do. The bricks should be laid by experienced bricklayers, not by amateurs.

"After the brick are laid the contractor will start culling. Then you and your inspectors should carefully go over them, marking all soft[1] bricks to be taken out and rejected; all kilnmarked bricks to be turned over, and if not satisfactory to be taken out and used for pinning in; all overburned bricks,[2] which are burned to a cinder to be rejected. All underburned bricks, which, in your opinion, will not make a satisfactory pavement, to be rejected. All bronzed bricks (which have the appearance of overburned brick but this on one side only) to be turned over, and if satisfactory allowed to remain in the pavement.

"Be sure that you have culled all of the bricks before the pavement is rolled, for after the pavement is rolled if much culling is done you are liable to have a rough pavement. After the pavement is rolled go over same and mark all broken and spalled bricks, to be taken out or turned over.

"Be careful of all high and low bricks in the pavement, for same will wear badly when the road is finished.

"Be sure that your bricks are laid at right angles to the curb and are not wavy as to line.

"In no case allow any 'Dutchman'[3] in your pavement except on curves where absolutely necessary.

[1] Soft brick are found by sprinkling the pavement lightly; the soft or under-burned brick will absorb the moisture, rapidly becoming dull, while the good brick still glisten with the water.

[2] Over-burned brick are known by their color, which is much darker than the average.

[3] "Dutchman." Brick chipped to wedge shape to fill in between radial courses on curves.

"**Grouting.**—The grouting of the pavement is its life, and the greatest care must be used. Insist that all grout be placed on the pavement by the use of scoops from a box with unequal legs, or better still it should be mixed in a machine grout mixer with a spout delivery.

"The grout should be mixed in small quantities and of the exact proportions. The sand should be sharp, not too coarse nor too fine. Care should be taken in using lake sand, as same is probably not sharp and too heavy for the grout. As soon as the grout reaches the pavement it should, at once, be pushed into the joints by means of brooms or squeegees.

"It is best to use brooms on the first grouting and a squeegee on the second and third groutings.

"Be sure that the joints are well filled in the first grouting, and do not let the grout escape over the edging and be lost.

"Follow closely with the second grouting, otherwise the two groutings will not unite.

"Be careful that the second grouting does not overlap the first. After the second grouting examine the pavement carefully and, if necessary, put on a third grout to get flush joints.

"The pavement should be completely covered with grout and all joints should be well filled before you pass on same.

"Allow enough time for the grout to obtain initial set, and cover pavement with a layer of sand to protect same from the weather; and pavement should be kept wet for, at least, twenty-four hours.

"In no case permit traffic on the pavement under ten days; longer, if possible.

"**Expansion Joints.**—Be careful in removing the expansion joint boards that you do not disturb the pinning-in bricks and break the bond. We found it advisable to use two wedge-shaped boards to make the expansion joints and loosen up the back one as soon as grouting was started.

"In pouring the asphalt filler be sure that the joints are absolutely clean the full depth. This is very important, or, otherwise, you will have cracks in the pavement. The joints are to be flushed with asphalt."

AUTHOR'S NOTE: These instructions were written in 1912. Premolded asphalt joints are practically universally used today and overcome the dangers mentioned above.

CULVERTS

Culverts are usually constructed before the road is graded. They should be completed well in advance of the macadam, because even though the back-fill is carefully tamped there is bound to be some additional settlement under traffic action, and if the macadam is laid over a fresh back-fill depressions are sure to develop which, if not repaired, make "thank-you-marms" in the road.

Cast-Iron Pipe.—Trenches for pipe are dug the required depth, making the bottom wide enough to allow the joints to be properly

calked. This requires a trench 18″ to 24″ wider than the pipe diameter, i.e., for a 12″ pipe the trench is 30″ to 36″. Bell holes are dug as shown in Fig. 144, so that the pipe will have a uniform bearing its entire length. At no point should it rest directly on boulders or ledge rocks. If the foundation is soft the pipe should be laid on a concrete base. For ordinary soils the only precaution the inspector need take is to prevent backfill under the pipe.

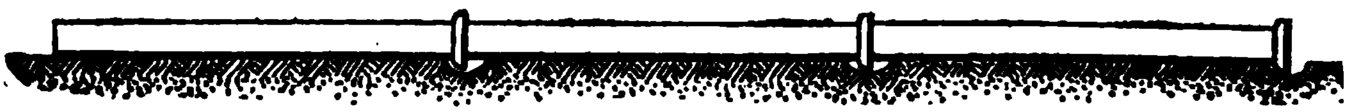


FIG. 144.

Unless the foreman is alert the trench is often excavated too much in some places, which are then back-filled. This is bad practice except where boulders are encountered which must be removed and the cavities back-filled with good material.

Pipe.—The pipe is inspected for flaws; it is then placed in the trench with the bell end upstream. At each joint the spigot

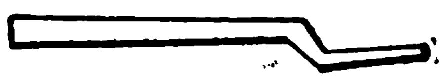


FIG. 145.—Steel caulking tool.

end is placed in the bell and forced against the shoulder, making a tight joint. The pipe is then lined correctly and a gasket of jute or oakum driven into the joint with an iron calking tool having a 2″ to 3″ offset, as shown in Fig. 145. The balance of the joint is then filled with a 1 to 1 cement mortar.

The trench is then back-filled, care being taken not to throw the pipe out of line; the back-fill must be well tamped in layers

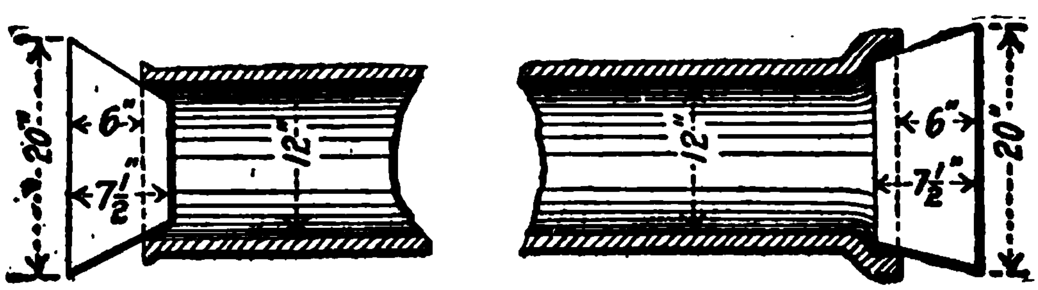


FIG. 146.

not exceeding 6″, using heavy paver's rammers. A good working rule is to use two of the best men on the job tamping and the laziest man on the force throwing dirt to them.

Head-Walls for Culverts.—The face of the head-wall should extend beyond the end of the pipe, as it is difficult to get a good-looking connection if it is flush with the end.

Figure 146 shows a convenient plug form for this extension. This plug is set into the end of the pipe and can be readily removed; the resulting head-wall being pleasing in appearance. The head-wall form can, also, be readily skewed (set at an angle with the pipe) if required.

CONCRETE CULVERTS

Excavation.—The trench is dug to the required depth; if the material will stand vertically no back forms are necessary, and the width of the trench is made the width of the out to out dimensions of the culverts. If back forms are needed the trench is usually made 2 feet wider. If running water is encountered which can not be temporarily dammed, or diverted, the trench is made wide enough to flume the stream through on one side of the back forms for small culverts, or between the abutments for larger span structures.

Back-fill.—The back-fill is made as for cast-iron pipe except that it should not be deposited on the fresh top of a culvert within twenty-four hours of laying the concrete.

Forms.—Forms should be true to shape and constructed of planed tongue and groove or carefully sized lumber, for the exposed surfaces. Face form lumber should never be less than 7/8 in. thick and should be well ribbed. They should be water-tight, as otherwise the fine material will run out of the face of the concrete and leave a rough "pop-corn" surface. They must be well braced to prevent bulging. Triangular or feather-edged grooved moldings are placed in the angles of the forms to shape them satisfactorily.

Removal of Forms.—The length of time that the forms should remain in place is a matter of judgment; it depends upon the cement and weather conditions.

The author's practice is as follows:

Head-walls or parapet forms are removed within thirty-six hours in dry weather or within forty-eight hours in damp, cold weather, in order to rub down the surfaces.

Low side-wall forms for spans of 2′ to 3′, where the deck is constructed later, may be removed in 36 to 48 hours.

Trunk forms for small culverts 2′ to 3′ span may be removed in from 3 to 7 days.

Trunk forms for medium culverts up to 10′ span 7 to 14 days.

Deck forms for spans above 10′ may be removed in from 14 to 28 days.

Any unusual load, such as a roller, should not be allowed over a new culvert of even a small span in less than seven days, unless precautions are taken to distribute the pressure by planking the back-fill, or otherwise, and on the larger structures a time limit of three to four weeks is advisable.

Amount of Cement, Sand, and Stone required.

Table 62, page 623 gives these amounts for one yard of concrete. The following table gives the amount of stone, sand, and cement required for culverts similar to Plate 15, assuming that no embedded boulders are used in the sides and bottom. If boulders are used see footnote, Table 62.

MIXING AND PLACING CONCRETE

The strength of the concrete depends largely upon the thoroughness of the mixing and the water content.

The author's practice has been as follows:

Hand-Mixing. Cement and Sand.

3 turns dry .... 3d class concrete		(foundations and side walls)
4 " " .... 2d " "		(decks and parapets)

Add water and mix mortar.
Drench stone and turn stone and mortar.
3 times for 3d class concrete
4 " " 2d " "

Deposit in forms by dropping. Do not cast, as this separates the coarse and fine material. Use enough water to give a mixture that quakes like liver under the rammer (about 6 gals. per sack of cement).

Deposit in layers not over 6″ deep and ram each layer thoroughly; spade the concrete thoroughly, and work an excess of the fine stuff to the face of the forms by prying the larger fragments back from the form with a narrow spade or broad-tined fork.

Machine Mixing.—Culverts generally contain such a small quantity of concrete that machine-mining is rarely used. In case a batch-mixer is employed, the inspection is simplified to checking the quantities of cement, sand, and stone in each charge. If a continuous mixer is used it is well to keep watch of the cement hopper, as the cement is liable to run low, feeding only a portion of the worm, or a large lump of cement may ride on top of the worm and hinder the feed; or the worm may become coated with damp cement which reduces the capacity. If the inspector watches the cement hopper the contractor will tend to the sand and stone hoppers.

Finishing Concrete.—If a smooth, marble-like surface is desired it can be obtained by rubbing down the surface before it has fully set with a cement sand brick moistened with water. If a rough sandpaper-like finish is wanted it can be secured by rubbing with a wooden float moistened with water. This finish is not as apt to hair-check as the smooth finish.

Freshly laid concrete should be protected from a hot sun by covering it with canvas, or blankets, and wetting it down frequently for four or five days. No plastering of surfaces should be allowed after the cement has set. If, however, it has been badly hair-checked from heat the defect can usually be remedied by rubbing with a carborundum brick. Freshly laid concrete must be protected from frost. A satisfactory method is to cover with canvas and a thick layer of manure or straw. If the concrete has been frost-pitted, on the surface only, bush hammering will give a rough stone finish, pleasing in appearance. No culvert work should be allowed in continued cold weather, as it is difficult to get a good finish and in roadwork there is no necessity of doing this work in the winter. Concrete inspection must be *continuous.*

CONCLUSION

For obvious reasons the inspection of construction is generally the weak point in Municipal and State Engineering undertakings. It is often due to the employment of inferior inspectors, and frequently to the impossibility of even good inspectors controlling certain contractors. The work is rarely bad, but it will not be as strong nor as lasting as a first-class job, and if such conditions are foreseen, and can not be avoided, it is, perhaps, best to design the work stronger than would otherwise be required, as this seems to be the only practical method of meeting a recognized evil.

TABLE 67.—CONCRETE CULVERTS

1.5′ high × 2.0′ wide								
Length Feet	Concrete Cubic Yards		Paving Square Yards	Ex. Met. Square Feet	Cement Barrels	Sand Cubic Yards	Crushed Stone Cubic Yards
	Second	Third					
20	2.2	5.6	6.4	80	8.4	3.6	7.2
21	2.2	5.8	6.4	84	8.6	3.7	7.4
22	2.3	6.1	6.4	88	9.0	3.9	7.8
23	2.4	6.3	6.4	92	9.3	4.1	8.1
24	2.5	6.5	6.4	96	9.7	4.2	8.3
25	2.5	6.7	6.4	100	9.9	4.3	8.5
26	2.6	6.9	6.4	104	10.2	4.4	8.8
27	2.7	7.2	6.4	108	10.6	4.6	9.2
28	2.8	7.4	6.4	112	10.9	4.8	9.5
29	2.8	7.6	6.4	116	11.1	4.9	9.6
30	2.9	7.8	6.4	120	11.5	5.0	9.9
31	3.0	8.1	6.4	124	11.9	5.2	10.3
32	3.1	8.3	6.4	128	12.2	5.3	10.6
33	3.1	8.5	6.4	132	12.4	5.4	10.8
34	3.2	8.7	6.4	136	12.7	5.6	11.0
35	3.3	8.9	6.4	140	13.1	5.7	11.3
36	3.4	9.2	6.4	144	13.5	5.9	11.7
37	3.4	9.4	6.4	148	13.7	6.0	11.9
38	3.5	9.6	6.4	152	14.0	6.1	12.1
39	3.6	9.8	6.4	156	14.5	6.3	12.4
40	3.6	10.1	6.4	160	14.8	6.4	12.7
41	3.7	10.3	6.4	164	15.1	6.5	13.0
42	3.8	10.5	6.4	168	15.4	6.7	13.3
43	3.9	10.7	6.4	172	15.7	6.8	13.5
44	3.9	10.9	6.4	176	15.9	6.9	13.7
45	4.0	11.2	6.4	180	16.4	7.1	14.1
46	4.1	11.4	6.4	184	16.7	7.2	14.4
47	4.2	11.6	6.4	188	17.0	7.4	14.7
48	4.2	11.8	6.4	192	17.2	7.5	14.8
49	4.3	12.1	6.4	196	17.6	7.7	15.2
50	4.4	12.3	6.4	200	18.0	7.8	15.5

TABLE 67.—CONCRETE CULVERTS.—*Continued*

2′ high × 2′ wide							
Length Feet	Concrete Cubic Yards		Expanded Metal Square Feet	Paving Square Yards	Portland Cement Barrels	Sand Cubic Yards	Crushed Stone Cubic Yards
	Second	Third					
20	2.4	7.1	80	9.8	10.1	4.4	8.8
21	2.4	7.3	84	9.8	10.4	4.5	9.0
22	2.5	7.6	88	9.8	10.8	4.7	9.4
23	2.6	7.9	92	9.8	11.2	4.9	9.7
24	2.7	8.1	96	9.8	11.5	5.0	10.0
25	2.7	8.4	100	9.8	11.8	5.2	10.3
26	2.8	8.6	104	9.8	12.2	5.3	10.6
27	2.9	8.9	108	9.8	12.6	5.5	10.9
28	3.0	9.2	112	9.8	13.0	5.7	11.3
29	3.0	9.4	116	9.8	13.2	5.8	11.5
30	3.1	9.7	120	9.8	13.6	6.0	11.9
31	3.2	9.9	124	9.8	14.0	6.1	12.1
32	3.3	10.2	128	9.8	14.4	6.3	12.5
33	3.3	10.5	132	9.8	14.7	6.4	12.8
34	3.4	10.7	136	9.8	15.0	6.6	13.0
35	3.5	11.0	140	9.8	15.4	6.8	13.4
36	3.6	11.2	144	9.8	15.8	6.9	13.7
37	3.6	11.5	148	9.8	16.1	7.1	14.0
38	3.7	11.8	152	9.8	16.5	7.2	14.4
39	3.8	12.0	156	9.8	16.8	7.4	14.7
40	3.9	12.3	160	9.8	17.3	7.6	15.0
41	3.9	12.5	164	9.8	17.5	7.7	15.2
42	4.0	12.8	168	9.8	17.9	7.9	15.6
43	4.1	13.1	172	9.8	18.3	8.0	16.0
44	4.2	13.3	176	9.8	18.6	8.2	16.2
45	4.2	13.6	180	9.8	18.9	8.3	16.5
46	4.3	13.9	184	9.8	19.4	8.5	16.9
47	4.4	14.1	188	9.8	19.7	8.6	17.2
48	4.4	14.4	192	9.8	20.0	8.8	17.4
49	4.5	14.6	196	9.8	20.4	8.9	17.7
50	4.6	14.9	200	9.8	20.8	9.1	18.1

TABLE 67.—CONCRETE CULVERTS.—*Continued*

2′ high × 3′ wide							
Length Feet	Concrete Cubic Yards		Expended Metal Square Feet	Steel Pounds	Portland Cement Barrels	Sand Cubic Yards	Crushed Stone Cubic Yards
	Second	Third					
20	2.3	7.6	100	78	10.5	4.6	9.2
21	2.4	7.9	105	81	11.0	4.8	9.6
22	2.5	8.2	110	85	11.4	5.0	9.9
23	2.6	8.5	115	88	11.8	5.2	10.3
24	2.6	8.8	120	91	12.1	5.3	10.6
25	2.7	9.1	125	95	12.5	5.5	10.9
26	2.8	9.4	130	98	13.0	5.7	11.3
27	2.9	9.7	135	101	13.4	5.9	11.7
28	3.0	9.9	140	105	13.7	6.0	12.0
29	3.1	10.2	145	108	14.1	6.2	12.3
30	3.2	10.5	150	112	14.6	6.4	12.7
31	3.3	10.8	155	115	15.0	6.6	13.1
32	3.4	11.1	160	118	15.4	6.8	13.4
33	3.5	11.4	165	122	15.9	7.0	13.8
34	3.6	11.7	170	125	16.3	7.2	14.2
35	3.7	12.0	175	128	16.7	7.3	14.6
36	3.8	12.2	180	132	17.0	7.5	14.8
37	3.9	12.5	185	135	17.5	7.7	15.2
38	3.9	12.8	190	139	17.8	7.8	15.5
39	4.0	13.1	195	142	18.2	8.0	15.9
40	4.1	13.4	200	145	18.6	8.2	16.2
41	4.2	13.7	205	149	19.0	8.4	16.6
42	4.3	14.0	210	152	19.5	8.6	17.0
43	4.4	14.3	215	156	19.9	8.7	17.3
44	4.5	14.5	220	159	20.2	8.9	17.6
45	4.6	14.8	225	162	20.7	9.1	18.0
46	4.7	15.1	230	166	21.1	9.2	18.4
47	4.8	15.4	235	169	21.5	9.4	18.7
48	4.9	15.7	240	172	21.9	9.6	19.1
49	5.0	16.0	245	176	22.4	9.8	19.5
50	5.1	16.3	250	179	22.8	10.0	19.8

TABLE 67.—CONCRETE CULVERTS.—*Continued*

2′ high × 4′ wide							
Length Feet	Concrete Cubic Yards		Expanded Metal Square Feet	Steel Pounds	Portland Cement Barrels	Sand Cubic Yards	Crushed Stone Cubic Yards
	Second	Third					
20	2.7	8.4	120	78	11.8	5.2	10.3
21	2.8	8.7	126	81	12.3	5.3	10.7
22	2.9	9.0	132	85	12.7	5.6	11.0
23	3.1	9.3	138	88	13.2	5.8	11.5
24	3.2	9.7	144	91	13.8	6.0	12.0
25	3.3	10.0	150	95	14.2	6.2	12.3
26	3.4	10.3	156	98	14.6	6.4	12.7
27	3.5	10.6	162	101	15.0	6.6	13.1
28	3.6	10.9	168	105	15.5	6.8	13.4
29	3.7	11.2	174	108	15.9	6.9	13.8
30	3.8	11.5	180	112	16.3	7.1	14.2
31	3.9	11.9	186	115	16.8	7.4	14.6
32	4.0	12.2	192	118	17.3	7.6	15.0
33	4.2	12.5	198	122	17.8	7.8	15.5
34	4.3	12.8	204	125	18.3	8.0	15.9
35	4.4	13.1	210	128	18.7	8.2	16.2
36	4.5	13.4	216	132	19.1	8.4	16.6
37	4.6	13.8	222	135	19.6	8.6	17.1
38	4.7	14.1	228	139	20.1	8.7	17.4
39	4.8	14.4	234	142	20.5	9.0	17.8
40	4.9	14.7	240	145	20.9	9.1	18.2
41	5.0	15.0	246	149	21.4	9.4	18.6
42	5.2	15.3	252	152	21.9	9.6	19.1
43	5.3	15.6	258	156	22.3	9.8	19.4
44	5.4	16.0	264	159	22.9	10.0	19.9
45	5.5	16.3	270	162	23.3	10.2	20.2
46	5.6	16.6	276	166	23.7	10.4	20.6
47	5.7	16.9	282	169	24.1	10.6	21.0
48	5.8	17.2	288	172	24.6	10.8	21.3
49	5.9	17.5	294	176	25.0	10.9	21.7
50	6.0	17.8	300	179	25.4	11.1	22.1

TABLE 67.—CONCRETE CULVERTS.—*Continued*

4′ high × 4′ wide							
Length Feet	Concrete Cubic Yards		Expanded Metal Square Feet	Steel Pounds	Portland Cement Barrels	Sand Cubic Yards	Crushed Stone Cubic Yards
	Second	Third					
20	2.7	14.5	120	87	18.1	8.1	15.9
21	2.8	15.0	126	90	18.7	8.3	16.5
22	2.9	15.4	132	94	19.2	8.6	17.0
23	3.1	15.9	138	97	20.0	8.9	17.6
24	3.2	16.4	144	100	20.6	9.2	18.2
25	3.3	16.8	150	104	21.1	9.4	18.7
26	3.4	17.3	156	107	21.8	9.7	19.2
27	3.5	17.7	162	111	22.3	9.9	19.7
28	3.6	18.2	168	114	22.9	10.2	20.2
29	3.7	18.7	174	117	23.5	10.5	20.8
30	3.8	19.1	180	121	24.1	10.7	21.2
31	3.9	19.6	186	124	24.7	11.0	21.8
32	4.0	20.1	192	128	25.3	11.3	22.4
33	4.2	20.5	198	131	26.0	11.6	22.9
34	4.3	21.0	204	134	26.6	11.9	23.5
35	4.4	21.4	210	138	27.1	12.1	24.0
36	4.5	21.9	216	141	27.8	12.4	24.5
37	4.6	22.4	222	145	28.4	12.6	25.1
38	4.7	22.8	228	148	28.9	12.9	25.5
39	4.8	23.3	234	151	29.6	13.1	26.1
40	4.9	23.8	240	155	30.2	13.4	26.6
41	5.0	24.2	246	158	30.7	13.7	27.1
42	5.1	24.7	252	162	31.4	14.0	27.7
43	5.3	25.2	258	165	32.1	14.3	28.3
44	5.4	25.6	264	168	32.6	14.5	28.8
45	5.5	26.1	270	172	33.3	14.8	29.3
46	5.6	26.5	276	175	33.8	15.0	29.8
47	5.7	27.0	282	179	34.4	15.3	30.3
48	5.8	27.5	288	182	35.1	15.6	30.9
49	5.9	27.9	294	185	35.6	15.8	31.4
50	6.0	28.4	300	189	36.2	16.1	31.9

TABLE 67.—CONCRETE CULVERTS.—*Continued*

3′ high × 5′ wide

Length Feet	Concrete Cubic Yards		Expanded Metal Square Feet	Steel Pounds	Portland Cement Barrels	Sand Cubic Yards	Crushed Stone Cubic Yards
	Second	Third					
20	4.0	12.4	140	83	17.5	7.7	15.2
21	4.2	12.8	147	86	18.1	7.9	15.7
22	4.4	13.3	154	90	18.9	8.3	16.4
23	4.6	13.7	161	93	19.5	8.6	17.0
24	4.7	14.1	168	96	20.1	8.8	17.4
25	4.9	14.5	175	100	20.7	9.1	18.0
26	5.1	14.9	182	103	21.4	9.3	18.5
27	5.3	15.4	189	106	22.1	9.6	19.2
28	5.4	15.8	196	110	22.6	9.9	19.7
29	5.6	16.2	203	113	23.3	10.2	20.2
30	5.8	16.6	210	117	23.9	10.5	20.8
31	5.9	17.0	217	120	24.5	10.7	21.2
32	6.1	17.4	224	123	25.1	11.0	21.8
33	6.3	17.9	231	127	25.9	11.3	22.4
34	6.5	18.3	238	130	26.5	11.6	23.0
35	6.6	18.7	245	134	27.1	11.8	23.5
36	6.8	19.1	252	137	27.7	12.1	24.0
37	7.0	19.5	259	140	28.4	12.4	24.6
38	7.2	19.9	266	144	29.0	12.7	25.1
39	7.3	20.4	273	147	29.6	12.9	25.7
40	7.5	20.8	280	150	30.3	13.2	26.2
41	7.7	21.2	287	154	30.9	13.5	26.8
42	7.8	21.6	294	157	31.5	13.7	27.3
43	8.0	22.0	301	161	32.1	14.0	27.8
44	8.2	22.4	308	164	32.8	14.3	28.4
45	8.4	22.9	315	167	33.4	14.6	29.0
46	8.5	23.3	322	171	34.1	14.8	29.5
47	8.7	23.7	329	174	34.7	15.1	30.0
48	8.9	24.1	336	177	35.3	15.3	30.6
49	9.1	24.5	343	181	36.0	15.6	31.2
50	9.2	24.9	350	184	36.5	15.9	31.6

TABLE 67.—CONCRETE CULVERTS.—*Continued*

4′ high × 5′ wide

Length Feet	Concrete Cubic Yards Second	Concrete Cubic Yards Third	Expanded Metal Square Feet	Steel Pounds	Portland Cement Barrels	Sand Cubic Yards	Crushed Stone Cubic Yards
20	4.0	15.8	140	88	21.0	9.2	18.4
21	4.2	16.3	147	92	21.7	9.6	19.0
22	4.4	16.8	154	95	22.5	9.9	19.7
23	4.6	17.2	161	99	23.1	10.2	20.2
24	4.7	17.7	168	102	23.7	10.5	20.8
25	4.9	18.2	175	105	24.5	10.8	21.4
26	5.1	18.7	182	109	25.2	11.1	22.1
27	5.3	19.2	189	112	26.0	11.5	22.7
28	5.4	19.7	196	116	26.6	11.7	23.3
29	5.6	20.2	203	119	27.4	12.1	23.9
30	5.8	20.7	210	122	28.1	12.4	24.6
31	5.9	21.2	217	126	28.8	12.7	25.1
32	6.1	21.7	224	129	29.5	13.0	25.8
33	6.3	22.1	231	133	30.2	13.3	26.3
34	6.5	22.6	238	136	30.9	13.6	27.0
35	6.6	23.1	245	139	31.5	13.9	27.6
36	6.8	23.6	252	143	32.3	14.2	28.2
37	7.0	24.1	259	146	33.0	14.5	28.8
38	7.2	24.6	266	150	33.8	14.9	29.5
39	7.3	25.1	273	153	34.4	15.1	30.1
40	7.5	25.6	280	156	35.2	15.5	30.7
41	7.7	26.1	287	160	35.9	15.8	31.3
42	7.8	26.6	294	163	36.6	16.1	31.9
43	8.0	27.0	301	167	37.2	16.4	32.5
44	8.2	27.5	308	170	38.0	16.7	33.1
45	8.4	28.0	315	173	38.7	17.0	33.8
46	8.5	28.5	322	177	39.3	17.3	34.3
47	8.7	29.0	329	180	40.1	17.6	35.0
48	8.9	29.5	336	184	40.9	18.0	35.6
49	9.1	30.0	343	187	41.6	18.3	36.3
50	9.2	30.5	350	190	42.2	18.6	36.8

TABLE 67.—CONCRETE CULVERTS.—*Continued*

5′ high × 5′ wide							
Length Feet	Concrete Cubic Yards		Expanded Metal Square Feet	Steel Pounds	Portland Cement Barrels	Sand Cubic Yards	Crushed Stone Cubic Yards
	Second	Third					
20	4.0	19.5	140	93	24.7	11.0	21.8
21	4.2	20.0	147	96	25.5	11.3	22.5
22	4.4	20.6	154	100	26.3	11.7	23.2
23	4.6	21.2	161	103	27.2	12.1	24.2
24	4.7	21.7	168	106	27.8	12.4	24.8
25	4.9	22.3	175	110	28.7	12.7	25.4
26	5.1	22.9	182	113	29.5	13.1	26.2
27	5.3	23.4	189	117	30.3	13.4	26.8
28	5.4	24.0	196	120	31.0	13.8	27.6
29	5.6	24.6	203	123	31.9	14.1	28.2
30	5.8	25.1	210	127	32.6	14.5	29.0
31	5.9	25.7	217	130	33.4	14.8	29.6
32	6.1	26.2	224	134	34.1	15.1	30.2
33	6.3	26.8	231	137	35.0	15.5	31.0
34	6.5	27.4	238	140	35.8	15.9	31.8
35	6.6	27.9	245	144	36.4	16.2	32.4
36	6.8	28.5	252	147	37.3	16.5	33.0
37	7.0	29.1	259	150	38.2	16.9	33.8
38	7.2	29.6	266	154	38.9	17.2	34.4
39	7.3	30.2	273	157	39.6	17.6	35.1
40	7.5	30.8	280	161	40.5	17.9	35.8
41	7.7	31.3	287	164	41.2	18.3	36.5
42	7.8	31.9	294	167	42.0	18.6	37.2
43	8.0	32.5	301	171	42.8	19.0	37.9
44	8.2	33.0	308	174	43.6	19.3	38.6
45	8.4	33.6	315	178	44.4	19.7	39.3
46	8.5	34.2	322	181	45.2	20.0	40.0
47	8.7	34.7	329	184	45.9	20.3	40.6
48	8.9	35.2	336	188	46.7	20.6	41.2
49	9.1	35.9	343	191	47.6	21.0	42.0
50	9.2	36.4	350	195	48.3	21.4	42.8

PART III

SPECIFICATIONS

The following clauses quoted from various sources are examples of current practice. They are not ideal but serve to show the points to be considered.

A specification should be complete, concise and clear as to the materials, manipulation and basis of measurement and payment. In preparing a specification it is convenient to have a general outline of points to be covered. Such an outline has been prepared by the U. S. Office of Public Roads to serve as a uniform basis for specifications for Federal Aid and is reproduced below. It is in the author's opinion a very good reminder of necessary requirements.

The usual size of page used for highway specifications is approximately 8½″ × 11″; this is an unwieldy size for field use; a size of 6″ × 9″ is much handier and is about the smallest dimension feasible on account of space required on the proposal bidding blanks. Where much work is being done the Specifications proper can be printed in pocket form 4¼″×6½″ and the Proposal, Contract and Bond separately on the usual 8½″×11″ size. This makes a convenient combination for both the field men and for Office filing of Contract records.

Repetitions should be avoided which is helped by segregating the requirements for materials in one part of the specification. Blanks to be filled out by hand are undesirable and should be reduced to a minimum. Loose leaf specifications are poor practice. Printed bidding sheets containing the estimated quantities of work reduce possible complications in connection with comparing bids.

No attempt is made in this book to discuss methods of bidding or the legal forms of contract as they must conform to local statutes.

UNITED STATES
DEPARTMENT OF AGRICULTURE

OFFICE OF THE SECRETARY

STANDARDS

GOVERNING THE FORM AND ARRANGEMENT OF

SPECIFICATIONS, AND ESTIMATES FOR FEDERAL AID PROJECTS

AS PROVIDED FOR IN THE RULES AND REGULATIONS OF THE SECRETARY OF AGRICULTURE FOR CARRYING OUT THE FEDERAL AID ROAD ACT

(EXCEPT SECTION 8 THEREOF)

ISSUED APRIL 28, 1917

TITLE-PAGE OR COVER FOR SPECIFICATIONS, ETC.

(NOTE.—The name of the State should appear at top of the title-page in bold-faced caps.)

NOTICE TO CONTRACTORS

Time and place of receiving and opening proposals.

Brief description of proposed work.

Place where plans and specifications may be examined or secured, and from whom information may be obtained.

Rights reserved to reject any or all proposals.

Any additional information desired.

NOTE.—The above information should be shown in the advertisement for proposals, and on the "Notice to contractors," which may be sent out to prospective bidders. It may be attached to the proposal if desired, should the proposal be a separate form, or may be attached to or bound with the specifications, immediately following the title-page, if the specifications, proposal, and contract are one volume.

SPECIFICATIONS

Definition of Terms

Definition of State, State highway department or commission, engineer, contractor, etc.

INSTRUCTIONS TO BIDDERS

Interpretation of approximate estimate.
Statement regarding right of engineer to increase or decrease quantities shown in proposal.
Bidders required to examine the plans, specifications, special provisions, etc., and also the site of the proposed work.
Bidders' attention called to necessity of being familiar with Federal, State, and local laws affecting the work.
Explanation of use of, or contents of, proposal form.
Instructions for filling in proposal form.
Requirements regarding signatures on proposals.
Prohibition of alteration, erasures, etc., on proposal forms.
Bidders' guaranty to accompany proposals.
Reference to form of guaranty required—Certified check, to whom payable, and amount indicated in proposal or percentage of contract required; or, proposal bond, form, amount indicated in proposal, and how executed.
Instructions for submitting or delivering proposals.
Delivery by mail and delivery in person.
Statement that proposals may or may not be withdrawn.
In case withdrawal is allowed, the bidder should be obliged to file his written request not later than the day previous to the opening of the proposals.
Opening of proposals.
Time and place and invitation to bidders to be present.
Disqualification of bidders.
No right to submit more than one proposal; collusion; unbalanced proposals; failure to carry out previous contracts; and lack of experience and capital.
Any additional clauses desired.

AWARD AND EXECUTION OF CONTRACT

Right reserved to reject any and all proposals and to waive technicalities.
Award of contract.
By whom, place, to whom, and when made.
Return of proposal guaranty.
How and when returned.
Contract bond required.
Reference to form furnished by State and to the amount shown in proposal or percentage of amount of contract required.
Execution of contract.
Time and place.
Failure to execute contract.
Restrictions relative to subletting or assigning contracts.
Statement relative to use of patented processes, materials, or methods.

GENERAL PROVISIONS

Scope of work to be done.
General statement relative to performing work and furnishing labor, equipment, etc., except as provided in the "Special provisions," in accordance with the plans, specifications, and contract.
Necessary State and local permits and licenses to be secured by contractor.
No deviation from plans, specifications, etc., by contractor.
Interpretation of plans, etc.

Figured dimensions to govern.

Special work.

Clause calling attention to special provisions for work or special requirements, not covered by the standard specifications, designating in this clause whether the special provisions will be found in the specifications, or will be attached to or bound with the proposal.

Alteration of work.

Clause regarding right of engineer to alter plans or character of work within reasonable limits.

Additional work.

Provision referring to additional work due to increase of quantities which is to be paid for at contract unit prices.

Extra work or force account.

Clause pertaining to work for which no price is named in the proposal and which is to be paid for at a price to be agreed upon or on a percentage basis, at prices to be agreed upon for labor, rentals, materials, etc. It should be specifically shown to which items the percentage applies.

Unauthorized work.

No payment made therefor.

Prosecution or progress of the work.

Limitation of operations.

Character of v orkmen and equipment.

Cooperation of contractor required.

Clause requiring contractor to have copy of plans, specifications, etc., and authorized representative to receive and obey orders of engineer on the work at all times.

Laws to be observed.

Sanitary provisions.

Observance of rules of boards of health.

Public convenience and safety.

Traffic regulations, nonobstruction of sidewalks, fire hydrants, etc., use of barricades, danger, warning and detour signs, precautions in the use of explosives.

Preservation and restoration of public utilities, property, trees, monuments, etc.

To be preserved and restored and made good if damaged or injured.

Contractor's responsibility for damage to persons and property.

Contractor's responsibility for damage to work.

Contractor's responsibility for sections or portions of roadway opened to traffic prior to final approval or acceptance.

Contractor required to restore surfaces opened by permit and basis of payment therefor, also provision for failure to restore surface openings.

Tests of samples of materials.

Statement of where and by whom tests will be made.

Quality of materials.

Statement that materials shall maintain qualities equal to the requirements of the specifications, or to approved samples.

Storage of materials.

Use of materials found on work.

Statement relative to use of any stone, gravel, sand, etc., found in excavation.

Disposal of materials, structures, etc., found on work and not used in the construction.

Lines, grades, and measurements.

To be given by engineer, and stakes and markings to be preserved by contractor.

Crown or cross-section of roadway.

To be as shown on typical cross-section and only changed where drainage or other conditions make it necessary.

Authority and duties of assistants, inspectors, etc., and the limitations of such authority and duty.

Engineer as referee in case of disputes.

Inspection of materials and work.

Defective materials and work.

Clause as to disposition thereof.

Failure to remove or renew defective materials or work.

Final cleaning up.

Clause covering removal of temporary structures and excess material and condition in which the roadway shall be left upon completion.
Suspension of work.
Authority for, reasons—fault of contractor, bad weather, etc.
Method of computing the time allowance for completing the work.
Failure to complete work on time.
Liquidated damages to be collected.
Annulment of contract.
Conditions under which contract may be annulled and procedure thereof.
Measurement of quantities.
Scope of payments.
Statement that payments made for all work done shall be full compensation for such work, including all claims of any character, and such payments do not constitute acceptance of the work.
Partial payments.
Method of payment.
Approval and final payment or acceptance and final payment.
No waiver of legal rights.
Statement regarding right of State to show true character of estimates should error be discovered, etc.
Any additional clauses desired.

CONSTRUCTION DETAILS

Excavation and Embankment

Description of work included under excavation, such as clearing and grubbing, excavation of roadway, driveways, intersections, ditches, etc., and the making of embankments.
Clearing and grubbing.
Specific requirements.
Removal of structures, obstructions, etc.
Specific requirements.
Roadway excavation.
Specific requirements.
Excavation for structures.
Specific requirements, including back filling.
Embankment.
Specific requirements.
Disposal of surplus material.
Specific requirements.
Borrow excavation.
Specific requirements.
Overhaul of excavation.
Specific requirements.
Sub-grade.
Specific requirements, including preparation, removal, and replacing of defective material, protection, and acceptance.
Shoulders.
Specific requirements.
Method of determining excavation quantities.
A statement of how quantities shall be measured.
Basis of payment.
Statement relative to compensation for excavation and its various subdivisions, and whether compensation is made collectively or separately.

NOTE.—When several similar types of constructions are set forth in the same set of specifications, such as several kinds of pipe culverts or pavements, each should be covered separately in accordance with the outlines indicated in the following.

SUB-BASE

Any broken stone, gravel, or other material used to replace unsuitable sub-grade material or to support the base course.
Description.
Materials.
Construction methods.
Basis of payment.

BASE COURSES OR FOUNDATIONS FOR PAVEMENTS

.... **Base Course**

Insert name

Description.
Materials.
Stone, sand, screenings, etc.
Construction methods.
Placing, rolling, etc.
Basis of payment.
Repeat the same outline for each kind of base course.

SURFACE COURSES OR PAVEMENTS

.... **Surface Course (or Pavement)**
Insert name

Description.
Materials.
Construction methods.
Basis of payment.
Repeat the same outline for each kind of surfacing.

CONCRETE

General description, classification, and statement of forms of construction in which each class of concrete is to be used.
Materials.
Specify composition and materials for each class.
Construction methods.
Basis of payment.

REINFORCEMENT

Description.
Describe each kind in order with the methods for placing.
Basis of payment.

MASONRY

.... **Masonry**
Insert name

Description.
Materials.
Construction methods.
Basis of payment.
Repeat the same outline for each of the other kinds of masonry.

DRAINAGE STRUCTURES

Concrete and Masonry Culverts, End Walls, Retaining Walls, Catch Basins, Drop Inlets, Etc.

Statement that all concrete and masonry culverts, end walls for pipe culverts, retaining walls, catch basins, drop inlets, etc., shall be built of the class of concrete or kind of masonry indicated and according to the plans and specifications therefor.
Basis of payment.

PIPE CULVERT

....
Insert name

Description.
Materials.
Construction methods.
Basis of payment.
Repeat the same outline for each kind of pipe culvert.

UNDERDRAINS

....................**Underdrains**
Insert name

Description.
Materials.
Construction methods.
Basis of payment.
Repeat the same outline for each kind of underdrain.

GUTTERS

Description.
Materials.
Construction methods.
Basis of payment.
Repeat the same outline for each kind of gutter.

CURBING

Description.
Materials.
Construction methods.
Basis of payment.
Repeat the same outline for each kind of curb.

GUARDRAIL OR FENCING

..................**Guardrail**
Insert name

Description.
Materials.
Construction methods.
Basis of payment.
Repeat the same outline for each kind of railing or fencing.

MONUMENTS

Description.
Materials.
Construction methods.
Basis of payment.

RIPRAP

Description.
Materials.
Construction methods.
Basis of payment.

CRIBBING

Description.
Materials.
Construction methods.
Basis of payment.

PILING

Description.
Materials.
Construction methods.
Basis of payment.

STRUCTURAL STEEL AND IRON

Description.
Materials.
Fabrication.
Construction methods.
Basis of payment.

SURFACE TREATMENTS

Description.
Materials.
Methods of application.
Sweeping, applying, and covering.
Basis of payment.

MISCELLANEOUS ITEMS

..................Items
Insert name.

Description.
Materials.
Construction methods.
Basis of payment.
Repeat the same outline for each item desired.

MATERIAL DETAILS

NOTE.—Should it be desired to group the specifications for all materials, they should be inserted at this place and appropriate references made thereto under the various subdivisions in "Construction details." The materials should be grouped in classes and placed in the following order:

Cementing materials.
Portland cement, lime, etc.
Water.
Fine aggregate.
Filler dust, sand, grit, etc., for all purposes.
Coarse aggregate.
Stone, gravel, slag, etc., for all purposes.
Telford and quarry stone, etc.
Masonry stone, etc.
Paving brick and blocks.
Bituminous materials.
Nonbituminous binders.
Culvert pipes, drain tiles, etc.
Cast iron, corrugated metal, concrete, vitrified clay, etc.
Metal reinforcement.
Bars, mesh, expanded metal, etc.
Structural steel.
Structural shapes, fabricated steel, etc.
Miscellaneous iron and steel.
Castings, special wrought work, etc.
Treated timbers.
Untreated timbers.
Paints, oils, etc.
Monuments.
Miscellaneous materials.
Fencing wire, cables, pipe rail, etc.

SPECIAL PROVISIONS

Supplementing the specifications for the construction of.................
Give the identification of proposed work, such as road name, number, job number, etc.

Under this heading should be placed such provisions or requirements as pertain to the particular contract proposed, and are not standard or common to all work for which the general specifications may have been prepared, such as:

Materials, etc., furnished by the State.
All materials, equipment, or other facilities for prosecuting the work, furnished by the State to the contractor, should be here listed, with conditions governing delivery, use, and return.

Statement relative to disposal of specific materials or structures found on the work and not to be used in the construction thereof.

NOTE.—Any "Special provisions" should be placed in this relative position, forming a part of the specificatons. If the proposal is separated

Item No.	Approximate Quantities	Items with Unit Bid Price Written in Words	Unit Bid Price		Amount Bid	
			Dollars	Cents	Dollars	Cents
1	....	Cu. yd. excavation for..............................per cu. yd....	....	....	....	....
	Total.........	....	....	....	....	....

when bids are invited, then the special provisions may be bound with the specifications or with the proposal; but in either case a proper clause should be inserted in the proposal calling the attention of the bidder to the fact that there are certain "Special provisions" which form a part of the specifications.

PROPOSAL

Spaces for name and address of bidder.

Detailed description of location of roadway, length and width of surfacing or pavement, referring to the plans, drawings, specifications, etc., by their titles and markings for identification.

NOTE.—If this proposal form is bound with the specifications and contract, it should be placed directly preceding the contract. If used as a separate form, the proposal may be attached to the contract, or a list of quantities with spaces for unit prices and amounts conforming to the outline indicated in the proposal may be shown in the contract as a part thereof, to be filled in at the time of its execution.

If the proposal bond form is used in place of the certified check, it should be attached to or furnished with the proposal form.

Address (as, "To the State Highway Department").

Declaration of the bidder that the only persons or parties interested in the proposal as principals are those named therein; that the proposal is made without collusion with any other person, firm, or corporation; that he has carefully examined the specifications, including special provisions, if any, and that he has made a personal examination of the site of the work; that he is to furnish all the necessary machinery, tools, apparatus, and other means of construction, and do all the work and furnish all the materials specified in the manner and time prescribed; that he understands that the quantities are approximate only and subject to increase or decrease, and the declaration of his willingness to perform any increased or decreased quantities of work at unit prices bid.

Itemized proposal showing the approximate quantities with spaces for unit prices bid, as:

Item 1:........cu. yd. Excavation at..... ($——) per cu. yd.

NOTE.—In case the above form is used, it may be used either with or without the quantities. If used without the quantities, the quantities should be listed under the "Special provisions."

or

NOTE.—Spaces should be left for filling in the unit prices both in words and figures, as indicated. The items of work should be numbered in the order and with the same units of measure shown in the specifications. The units of measure used should be as follows:

The cubic yard for all volumes except the gallon for bituminous materials when not weighed and the barrel for cement.

The square yard for all surface measurements except the square foot for wire mesh or expanded metal.

The foot for linear measurement.
The ton of 2000 pounds for weights except the pound for steel and casting.
A unit price each for any item desired.
Proposal to perform "force account or extra work."
Proposal to execute contract agreement and to begin and complete work on time.
State dates or number of days for beginning and completion.
Proposal stating the amount of contract bond.
Proposal for guaranty of work until final completion and acceptance.
Statement of inclosure of proposal guaranty, naming amount, and conditions of forfeiture.
Note whether certified check or bond.
Spaces for signatures, titles, and individual addresses.

PROPOSAL BOND

In case a proposal bond is used in lieu of a certified check, the form therefor should be attached to or furnished with the proposal form.

CONTRACT

The form of contract should be as short as consistent with legal requirements.

The "Notice to contractors," "Specifications," "Proposal," and "Plans" should be referred to and made a part of this agreement, and such reference should identify the specifications, plans, drawing, etc., by their specific markings.

The Federal Government is not to appear as party to this agreement.

CONTRACT BOND

INDEX

Itemized index to be placed at the end of the specifications instead of at this point if the foregoing documents are issued as separate pamphlets.

ESTIMATES

Estimates shall be made up in accordance with the order and units of measure indicated in the proposal form.

O

EXAMPLES OF GENERAL CLAUSES

The following general clauses are quoted from the U. S. Forest Road Specifications.

SPECIFICATIONS

DEFINITION OF TERMS

In interpreting these specifications, the following definitions shall prevail:

1. **Secretary.**—The Secretary of Agriculture of the United States.
2. **Chief Engineer.**—Chief Engineer of the Bureau of Public Roads, United States Department of Agriculture.
3. **District Engineer.**—District Engineer of the Bureau of Public Roads, in whose district the improvement is located.
4. **Engineer.**—Chief Engineer of the Bureau of Public Roads; District Engineer of the Bureau of Public Roads, in whose district the improvement is located; or a representative of the foregoing duly authorized to supervise the work.
5. **Inspector.**—An authorized assistant of the engineer, assigned to inspect any feature of the materials or workmanship entering into the improvement.
6. **Forest Official.**—A duly authorized representative of the Forest Service, United States Department of Agriculture.
7. **Contractor.**—The person, firm, partnership, or corporation, constituting one of the principals to the contract, undertaking to perform the work herein specified, or any lawful agent of such person, firm, partnership or corporation.
8. **Plans.**—The official approved plans, profiles, cross-sections, and other drawings, or exact reproductions thereof, which show the location, character, dimensions and details of the work to be done, and which are to be considered in the contract as coordinate with these specifications.
9. **Specifications.**—The directions, provisions and requirements contained herein, together with all written agreements made or to be made, pertaining to the method and manner of performing the work, or to the quantities and qualitites of materials to be furnished under the contract.
10. **Contract.**—The agreement between the Contractor and the Secretary of Agriculture covering the work to be performed, and including the plans and specifications.
11. **Laboratory.**—The laboratories of the Bureau of Public Roads or other laboratories designated by the Chief Engineer.

INSTRUCTIONS TO BIDDERS

Interpretation of Approximate Estimate.—Bidders are cautioned that the estimate of quantities attached hereto will serve, so far as this project is concerned, only for the purpose of comparing bids. The basis of payment on the contract will be the actual quantites of work performed in accordance with the plans and specifications, and if, upon the completion of the improvement the actual quantities should show either increase or decrease from the quantities given in the approximate estimate, the unit bid prices mentioned in the proposal will still prevail, except as otherwise provided herein.

Examination of Plans, Specifications and Site.—Bidders are required before submitting bids to examine carefully the site of the proposed work, as well as the proposal, plans, specifications, and contract form for the improvement contemplated. Professions of ignorance regarding the requirements for the work will in no way serve to modify the provisions of the contract.

Laws Affecting Public Work.—The attention of bidders is called to the necessity for being familiar with the various Federal, State and local laws, affecting the length of working days, employers' liabilities, Sunday work, etc., etc.

Proposal Forms.—In filling out proposal forms bidders shall be governed by the following provisions:

1. Proposals must be made on the blank form provided herewith. The

blank spaces in the proposal form, except as otherwise noted, must all be filled in correctly where indicated for each and every item for which a quantity is given, and no change shall be made either in the phraseology of or the items mentioned in the proposal form.

2. Proposals must be signed in ink by the bidder with the signature in full. When a firm is a bidder, the agent who signs the firm name to the proposal shall state, in addition, the names and addresses of the individuals composing the firm. When a corporation is a bidder, the person signing for it shall state under the laws of what state the corporation was chartered and the name, title, and address of the officer having authority under the by-laws to sign contracts. The proposal shall also bear the seal of the corporation, attested by its secretary. Anyone signing the proposal as agent must file with it legal evidence of his authority to do so. Post-office address, county and state, must be given after the signature.

3. Proposals that contain any omission, erasure, alteration of form, addition, item not called for in the engineer's estimate, conditional or alternate bids, or that show irregularities of any kind, may be rejected as informal.

4. Each proposal shall specify a unit bid price, written with ink in both words and figures, for each of the separate items as called for, and shall also show the products of the respective unit prices and quantities of work, written in figures with ink, in the column provided for that purpose. The gross bid, or sum of the various products, shall be shown, written in ink, on the line provided for such gross bid.

5. Any proposal which does not contain prices set opposite each of the several items for which there is an estimated quantity in the engineer's estimate, or any proposal which shall in any manner fail to conform to the conditions of the published notice inviting proposals, may be deemed informal and rejected.

6. Each proposal must be accompanied by a money deposit in an amount at least equal to five (5) per centum of the total amount of the proposal, in the form of cash, a draft, or a certified check, issued by a national or state bank, in good credit and payable at sight to the Secretary of Agriculture of the United States. Where a certified check is used, it shall bear the same signature as the signature which appears on the proposal which such check accompanies.

7. Each proposal shall be placed, together with the money deposit, in a sealed envelope so marked as to indicate its contents without being opened. This envelope shall then be placed in another which shall be sealed, and addressed as indicated in the notice to contractors. Proposals may be delivered either in person or by mail.

8. A bidder may withdraw his proposal, without prejudice to himself, provided a written request is filed at the address indicated above not later than the day before the bids are to be opened.

9. Proposals will be publicly opened and read at the time and place mentioned in the notice to contractors, and bidders are invited to be present at the opening. Proposals received after the time set for the opening will be returned to the bidder unopened.

Disqualification of Bidders.—The following causes will be considered sufficient to disqualify any bidder, and no proposals from disqualified bidders will be considered in the award of the contract:

1. Interest by the same persons in more than one proposal for one contract.
2. Collusion among or between bidders.
3. Unbalanced proposals; that is, proposals in which the price bid for one or more items does not bear the proper proportion to the total amount bid to do the whole of the work.
4. Lack of responsibility on the part of bidders. For example, it is probable that no bidder would be considered responsible who had failed to carry out any contract in which the U. S. Department of Agriculture had been directly or indirectly concerned.
5. Lack of experience or capital on the part of bidders. Evidence of experience, ability, and financial standing, as well as a statement regarding plant and machinery available may be required of any or all bidders.

AWARD AND EXECUTION OF CONTRACT

Consideration of Bids.—After the proposals are opened and read, the bid prices will be compared by the District Engineer, and the results of such

comparison will be immediately made public. Until the final award of the contract, however, the right will be reserved to reject any and all proposals and to waive technical errors.

Award of Contract.—The award of the contract, if it be awarded, will be to the lowest responsible bidder whose proposal shall comply with all requirements necessary to render it formal. For the purposes of award the correct summation of the products of the approximate quantities, herein stated, by the unit bid prices will be considered the amount of the bid. In no case will an award be made until all necessary investigations are made into the responsibility of the bidder to whom it is proposed to award the contract.

Return of Proposal Guaranty.—As soon as the bid prices have been compared, the District Engineer may, at his discretion, return the guaranty deposits accompanying such of the proposals as in his judgment would not be considered in making the award. All other proposal guaranties will be held until the contract has been awarded, after which they will be returned to the respective bidders whose proposals they accompanied, with the exception of the bidder to whom award has been made. After a satisfactory bond has been furnished and the contract has been approved and executed by the Secretary, the proposal guaranty which accompanied the successful bidder's proposal will be returned.

Contract Bond Required.—The bidder to whom the contract is awarded will be required to furnish bond to the amount of 50 % of the total contract price. The bond shall be furnished by a reputable bonding company, and shall be satisfactory to the Secretary and on the form provided herewith.

Execution of Contract.—The contract shall be signed by the contractor and satisfactory bond furnished within ten days after he has received notice of award. In case of failure on the part of the contractor, to enter into contract and furnish bond as above required, the guaranty accompanying his proposal will be forfeited to the United States Treasury. Award may then be made to the next lowest responsible bidder, the work be readvertised or constructed by day labor as the Secretary may decide.

Subletting or Assigning Contracts.—Award will be made with the understanding that the work awarded will be performed by the contractor to whom the award is made, with the assistance of workmen under his immediate superintendence, and the contract shall not be sublet either in whole or in part except with the written consent of the District Engineer.

The Use of Patented Processes, etc.—The bid prices shall include all charges for the use of patented processes, materials or methods, and for all other similar incidental charges not expressly provided for in the specifications.

GENERAL PROVISIONS

Scope of the Work to be Done.—The contractor will be required under these specifications to perform the following work:

1. To grade the roadway and to bring the surface to the lines, grades and typical cross-section shown on the plans and to do the work in accordance with the plans and specifications.

2. To do all clearing and grubbing, ditching, grading, shaping, surfacing and compacting; to make all excavations and embankments; to construct all paving, masonry, stone and timber work; to build all waterways, drains, ditches, bridges, and culverts; and to clear away all rubbish which may obstruct the roadway, ditches or waterways, whether such obstructions result from his operations or otherwise. In short, the contractor will be required to furnish all materials, implements and labor necessary, and to build and put in perfect condition for use the entire roadway with all appertaining structures, and shall leave the roadway and adjoining property in neat condition and free from rubbish or other waste materials.

3. To start the improvement at the part of the road designated by the engineer, and to conduct and complete the work in accordance with the plans and specifications as interpreted by the District Engineer. The unit prices mentioned in the proposal shall cover the cost of all materials and labor, except as otherwise herein provided.

Permits and Licenses.—Such permits, licenses, insurance policies, etc., as Federal, State or local laws necessitate in conducting the work, shall be provided by the contractor at his own expense.

Interpretation of Plans and Specifications.—The contractor shall not deviate from the plans and specifications in any particular without the

written authority of the District Engineer. In case of discrepancy between the plans and specifications, the plans shall govern, and in case of discrepancies on the plans between figured dimensions and scale, the figures shall govern.

Alterations.—The District Engineer shall have the right to make such reasonable alterations in the plans and specifications as in his judgment are necessary and desirable, and such alterations will not invalidate the contract. Reasonable alterations will be construed to mean alterations in the quantity location or extent of the work covered by the various items of the bid, but will not be construed to cover any alterations in the general character of the contract.

All orders making alterations in the plans and specifications shall be given by the District Engineer to the contractor in writing. Alteration work done by the contractor without such written orders, except in cases of emergency, and acknowledged as such by the District Engineer, will be at the contractor's own expense and will not be paid for under his contract for this work.

The final adjustment covering increases, decreases or eliminations caused by alterations will be made on the basis of the unit price bid for the item or items concerned and no allowance will be made on account of any claim for loss of profit due to the alteration.

Extra Work.—Alterations or changes in the plans and specifications and new or unforeseen items of work shall be classed as extra work when they can not be covered by any of the various items or combination of items for which there is a bid price.

The contractor shall furnish such labor, teams, equipment, supplies and materials as are necessary and perform such extra work as may be ordered in writing by the District Engineer whenever necessary for the proper completion or construction of the whole work herein contemplated; and he shall make no claim for extra work unless it shall have been done in obedience to such written order.

The contractor shall receive for such extra work the actual cost of all supplies and materials, including freight, furnished by him, as shown by his paid vouchers, and a reasonable rental charge previously agreed to in writing between the engineer and the contractor for the use of special equipment or machinery, such as steam rollers, steam shovels, concrete mixers, etc., required for the economical performance of the work; for such labor and teams as are necessary he shall receive the current prices in the locality, which shall have been previously agreed to in writing by the engineer and by the contractor, plus 15% of the cost of such labor and teams which shall be considered as full compensation for general supervision and the furnishing of small tools and ordinary equipment used on the contract, such as plows, Fresnos, wagons, graders, etc.

Unauthorized Work.—No payment will be made for work not required by the plans and specifications or authorized in writing by the District Engineer.

Progress of the Work.—The contractor shall begin work within ten days after receiving notice that the contract has been signed by the Secretary of Agriculture unless consent to begin at a later date is given in writing by the said Secretary, and shall so prosecute the work that the work done shall at all times bear approximately the same proportion to the total of the work required to be done under the contact that the time elapsed since the date upon which the work should have been begun bears to the total time allowed by the contract in which to do the whole of the work. Failure to comply with this requirement may result in the annulment of the contract as hereinafter provided.

Limitation of Operations.—The contractor shall so conduct his operations as to have under construction no greater length or amount of work than he can prosecute vigorously, and when in the judgment of the engineer such operations are being so spread out as to be detrimental to such vigorous prosecution, thereby endangering completion of the improvement within the contract time, he shall so advise the contractor in writing.

Character of Workmen and Equipment.—All workmen and equipment provided by the contractor shall be the best available for the kind of work being performed. Any person employed by the contractor, whom the engineer may deem incompetent or unfit to perform the work or who conducts himself in a disorderly manner, shall, upon the written instructions of the engineer, be discharged, and such person shall not be again employed on

the work. Failure by the contractor to provide adequate equipment or workmen may result in annulment of the contract as hereinafter provided.

Cooperation of Contractor Required.—The contractor shall keep a copy of the plans and specifications on the work at all times. He shall also remain on the work or provide an authorized representative to receive and carry out the instructions of the engineer. He shall provide all reasonable facilities to enable the engineer and inspectors to inspect the workmanship and materials entering into the work, and shall cooperate in the matter of setting and preserving stakes, benchmarks, etc., for controlling the work.

Laws to be Observed.—In prosecuting the work, the contractor shall exercise care to see that all laws are observed, both by himself and his employees. He shall also observe the rules and regulations of the United States Forest Service and the rules of the Board of Health, and shall take all reasonable steps to insure proper sanitation in connection with all of his activities.

Public Convenience and Safety.—In conducting the work the contractor shall interfere as little as possible with public traffic. He shall establish barricades and danger and detour signs wherever required by law or necessary for the safety or convenience of the public. He shall exercise especial precautions in the storage and use of explosives to warn away the public as well as to safeguard his employees.

Preservation of Property.—The contractor shall preserve from damage all property along the line of the work, the removal or destruction of which is not called for by the plans. This applies to public utilities, trees, monuments, fences, etc., and wherever such property is damaged due to the activities of the contractor, it shall be immediately restored to its original condition by the contractor and at his own expense.

Responsibility in Case of Damage to Persons or Property.—The responsibility for all damages to persons or property arising out of or on account of work done under this contract, shall rest upon the contractor, and he shall save the United States harmless from all claims made on account of such damages.

Responsibility for Damage to Work.—Any damage to the work before it is finally accepted, whether such damage is due to ordinary or extraordinary causes, shall be at once repaired by the contractor; except where a section or portion of road is opened to public traffic, with the approval of the engineer, before final acceptance, the contractor will not be expected to make good the ordinary wear due to traffic, provided no inherent defects in the work are disclosed; but this exception will not serve to release the contractor from responsibility for damage caused by storms, or otherwise, except as noted, to sections of road that have been opened to traffic.

Testing Materials.—Tests of materials to be used in the work shall be made in the laboratory designated in the "Definition of Terms" whenever such tests are required by the specifications or by the engineer. The contractor shall afford such facilities as the engineer may require for collecting and forwarding samples of materials to be tested as above required, and unless otherwise directed in writing by the engineer, the contractor shall not use in the work the materials represented by the said samples until he has received written notice from the engineer that he may do so.

Materials may be rejected by the engineer whenever, in his judgment, they fail to meet the requirements of the specifications, and when so rejected they shall be immediately removed from the work and disposed of as hereinafter specified.

Storage of Materials.—All materials intended for use in the work shall be so stored by the contractor as to prevent damage from exposure to the elements, admixture of foreign material, or from any other cause. The engineer will refuse to accept, or to sample for testing, any materials that are improperly stored.

Use of Materials Found on Work.—In the absence of special provision to the contrary, any stone, gravel, sand, etc., that may occur in excavations opened in grading the road, and may not be needed to make the fills shown on the plans, any timber, except as herein otherwise provided, that would necessarily be removed in making the improvement, or any existing structures that are to be replaced, may be used by the contractor, provided, and to the extent, that these materials are suitable for and required in the work. Materials found on the work, especially timber and existing structures, and necessarily removed, but not used by the contractor as provided above, shall be put into shape to be handled economically and neatly piled along the right-of-way, as herein provided or as the engineer may direct.

Lines, Grades and Measurements.—The contractor will be governed by such lines, grades and measurements as may be given by the engineer in laying out the work and by the engineer's determination of the quantities of work performed. Stakes and markings set or made by the engineer to mark out the work, shall be scrupulously preserved by the contractor. In case the activities of the contractor or his employees result in the destruction of such stakes or markings, an amount equal to the cost of replacing same will be deducted from subsequent estimates due the contractor whenever in the opinion of the engineer such destruction is due to the neglect or carelessness of the contractor or his employees.

Crown or Cross-section of Roadway.—The typical cross-section contained in the plans shall be implicitly followed as regards the crown or cross-section of the roadway except, that where considerations of drainage or other special conditions make it necessary or desirable to change the shape of the surface, or otherwise alter the shape of the cross-section, the engineer may alter this feature of the work to fit the conditions. Such an alteration, however, will not be considered as extra work.

Authority and Duties of Inspectors.—The District Engineer may appoint inspectors to inspect all materials used and all work done. Such inspection may extend to all or any part of the work and to the preparation or manufacture of the materials to be used. The inspectors will not be authorized to revoke, alter, enlarge, or relax the provisions of these specifications. An inspector is placed on the work to keep the engineer informed as to the progress of the work and the manner in which it is being done, also to call the attention of the contractor to any infringements upon plans or specifications. He will not be authorized to approve or accept any portion of the work or to issue instructions contrary to the plans and specifications. The inspector will have authority to reject defective material and to suspend any work that is being improperly done, subject to the final decision of the engineer.

The inspector will exercise such additional authority, only as may from time to time be especially delegated to him by the engineer.

Inspection of Materials and Work.—The engineer and his inspectors shall have free access to all parts of the work and to all materials intended for use in the work, and be given authority by the contractor to inspect the manufacture of such materials in the factories. Materials will be inspected and passed upon as promptly as practicable after they are delivered on the work, and none shall be used in the work until after approved by the engineer. The work will be inspected as it progresses, but failure to reject or condemn defective work at the time it is done will in no way prevent its rejection whenever it is discovered before the road is finally accepted, approved, and paid for.

Defective materials or work shall be removed from the site of the work and disposed of immediately after they are rejected. The disposition to be made of defective materials shall in all cases be such that the engineer can always satisfy himself that each parcel or lot of such material has been disposed of as claimed by the contractor.

Upon the failure of the contractor to remove and properly dispose of rejected material or work immediately after receiving formal notice, the engineer shall employ labor and remove such material or work, and charge the cost of same to the contractor and deduct it from his next estimate.

Final Cleaning Up.—When the work is completed the right-of-way, borrow pits, and all ground occupied by the contractor in connection with the work shall be cleared of all rubbish, excess materials, temporary structures and equipment, and all parts of the work shall be left in a neat and presentable condition.

Suspension of Work.—The engineer shall have authority to suspend the work on account of (1) Default of the contractor; (2) Unfavorable weather conditions; and (3) Any other condition which, in the judgment of the engineer, makes it impracticable to secure first-class results. The contractor shall immediately respect the written order of the engineer to suspend work wholly or on any particular section of the road. If it becomes necessary to stop the work for a protracted period the contractor shall open proper drainage ditches; erect temporary structures where necessary, prepare the road so there will be a minimum of interference with traffic, and take every precaution to prevent any damage or unreasonable deterioration of the work during the time it is closed down. If upon reopening the work any damage or deterioration has occurred due to negligence on the contractor's

part then he shall correct all such conditions at his own expense. In case of failure on the part of the contractor to carry out the provision of this section, the engineer shall do the necessary work and deduct the cost of the same from any moneys due or to become due the contractor, deducting it from the next estimate.

Time of Completion.—The engineer shall determine the weather working days and based thereon he shall compute the date of completion. Weather working days shall be considered as days or parts of days when, in the judgment of the engineer, it is practicable for the contractor to prosecute his work, Sundays, and legal holidays being excepted.

Should the contractor fail to complete the work within the time allowance mentioned in the notice to contractors, and as determined herein, the engineer will upon the arrival of the date of completion so notify the contractor and thereafter keep a record of overtime and deduct from any moneys due or coming due to the contractor, as determined by the engineer's estimates, an amount equal to the cost of maintaining the necessary force of engineers and inspectors on the work during the additional time necessary because of the contractor's delay, and this amount shall be considered as reasonable liquidated damages due the United States by the contractor for his failure to have finished the work within the time agreed.

Annulment of Contract.—The contract of which these specifications form a part may be annulled by the Secretary of Agriculture for any one of the following reasons:

1. Substantial evidence that the progress being made by the contractor is insufficient to complete the work within the specified time.

2. Failure on the part of the contractor to observe the requirements of these specifications.

3. Failure on the part of the contractor promptly to make good any defects in materials or workmanship that may be pointed out to him by the engineer.

Before the contract is annulled, the contractor and his bondsmen will first be notified in writing by the District Engineer of the conditions which make annulment of the contract imminent. Twenty days after this notice is mailed to the address given in the proposal, if in the judgment of the District Engineer no effective effort has been made by the contractor or his bondsmen to correct the condition complained of, the Secretary may declare the contract annulled, and notify the contractor and his bondsmen accordingly.

Upon receipt of a notice from the Secretary of Agriculture that the contract has been annulled, the contractor shall immediately discontinue all operations. The Secretary of Agriculture may then proceed with the work, in any lawful manner that he may elect, until it is finally completed.

When the work which was covered by the contract is thus finally completed, the total cost of the same will be computed. If this total cost is less than the contract price, any money due the contractor will be paid to him. If the total cost is greater than the contract price, the difference shall be paid either by the contractor or his bondsmen.

Measurement of Quantities.—The determination of the quantities of work performed will be made by the engineer and based on measurements taken by him or his assistants. In computing volumes the method of average end areas will be used for excavation and embankment. Other quantities will be computed in the units used in the proposal form, according to well recognized engineering principle, and no local rules or customs will be considered.

Payments.—Payments for each kind of work except as otherwise provided herein will be made on the basis specified for that particular item, and at the rate mentioned in the proposal. Payment of the amount computed on this basis and rate shall be payment in full for the work done including all claims of every character. No payments, however, shall constitute an acceptance of the work.

Partial payments will be made monthly, provided the work is progressing to the satisfaction of the engineer. The total amount of such payments at any time before final completion shall not exceed 85% of the value of the work done, as estimated by the engineer; and in estimating the value of the work done no materials that have been delivered but not used in completed work shall be included.

Whenever the work provided for by the contract shall have been completely performed on the part of the contractor, and all parts of the work have been approved by the District Engineer, a final estimate showing

the value of the work done will be prepared by the engineer as soon as the necessary measurements may be made. The amount of this estimate, less any sums that may have been deducted in accordance with the provisions of the contract, and less all previous payments, will be paid to the contractor within thirty days after the final estimate has been approved by the Chief Engineer.

No Waiver of Legal Rights.—The United States Government reserves the right, should an error be discovered in the estimate, or conclusive proofs of dishonesty on the part of the contractor, discovered in the work, after the final payment has been made, to claim and recover by process of law, such sums as may be sufficient to correct the error or make good the defects in the work resulting from the contractor's dishonesty.

SAMPLE CLAUSES COVERING MATERIALS AND MANIPULATION

The following sample clauses covering materials and manipulation are quoted from various sources.

MATERIALS

(NEW YORK STATE SPECIFICATIONS, 1914)

Materials of Construction

All materials proposed to be used in construction shall have due examination and pass all required tests before acceptance. Those which are to be tested by the Bureau of Tests at Albany shall have samples taken and submitted in accordance with the commission's instructions to its employees. Samples are to be taken of all sand, gravel, cement, concrete, bituminous material, stone, and all other pavement ingredients, of which the engineer in charge has not been notified that satisfactory samples have already been taken. None of this material is to be used until the written notification of acceptance is received by the engineer in charge of the contract, and then only so long as its quality remains equal to that of the accepted sample.

Portland Cement

0.1. All the cement used in the work shall be true Portland cement of well-known brands which have been in successful use on large engineering works in America for not less than two years and which are manufactured at works which have been in successful operation for at least one year.

0.2. Tests will be made as follows: first, for fineness; second, for constancy of volume; third, for time of setting; fourth, for tensile strength; fifth, for composition by chemical tests; sixth, for specific gravity.

The average result of the separate samples shall be the test for tensile strength of any lot. The samples of each lot shall be required to show uniform results in tests. Marked deviations from such results may be considered cause for rejection, even though test requirements may be otherwise fulfilled.

The results of the tests may be expected in 12 days afer shipment of samples.

Cement not satisfactory in the 7-day tests will be held awaiting the result of the 28-day tests before acceptance or rejection.

0.3. The cement shall meet the following requirements:

It shall be ground to such fineness that not less than 92% by weight shall pass through a No. 100 standard sieve of 10,000 meshes per square inch, and not less than 75% by weight shall pass through a No. 200 standard sieve of 40,000 meshes per square inch.

0.4. Pats of neat cement about 3 inches by 4 inches in size, ½ inch thick at the center, and tapering to a thin edge, shall be kept in moist air for a period of 24 hours.

NORMAL TESTS

Air Test: One of these pats is then kept in air at normal temperature for 28 days.

Water Test: Another pat is kept in water maintained as near 70 degrees Fahrenheit as practical for 28 days.

Accelerated Test: A pat is exposed in any convenient way in an atmosphere of steam, above boiling water, in a loosely closed vessel for 5 hours.

These pats are observed at intervals and, to satisfactorily pass the requirements, shall remain firm and hard and show no signs of distortion, checking, cracking or disintegration.

0.5. Cement shall not develop its initial set in less than 30 minutes, and shall develop a hard set in not less than 60 minutes nor more than 600 minutes, the determination being made with the Vicat needle apparatus from pastes of normal consistency, as follows:

The paste is molded upon a glass in a conical hard rubber mold 4 centimeters high; this cake is to set in moist air and a Vicat needle with a wire 1 millimeter in diameter and loaded to 300 grammes shall be placed upon it. When the needle ceases to pass a point 5 millimeters above the upper surface of the glass plate the initial set has taken place.

0.6. Briquettes of neat cement mixed 1 minute, in an air temperature between 65 and 70 degrees Fahrenheit and using water of about the same temperature, and put into the molds with fingers and trowel and kept in moist air at this temperature for 1 day of 24 hours, shall show an average tensile strength of one hundred and seventy-five (175) pounds per square inch.

Briquettes of neat cement mixed and molded as above and kept under above temperature for 1 day in moist air and 6 days in water shall show an average tensile strength of at least five hundred (500) pounds per square inch.

Briquettes of neat cement mixed and molded as above and kept under above temperature for 1 day in moist air and 27 days in water shall show an average tensile strength of six hundred (600) pounds per square inch.

Briquettes of 3 parts by weight of standard Ottawa sand and 1 part by weight of cement, mixed in the same manner as above and kept 7 days under the same conditions, shall show an average tensile strength of at least two hundred pounds (200) per square inch.

Briquettes of sand and cement mixed and molded as above and kept under above conditions for 28 days shall show an average tensile strength of at least two hundred and seventy-five (275) pounds per square inch.

In the above tests for tensile strength the briquettes must not show any retrogression in strength within the periods specified.

0.7. The Commission of Highways may cause chemical tests, or analyses, of cement to be made, and may reject any cement which shows any adulteration, or excess of ingredients, which in its judgment would be detrimental to the work.

The cement shall not contain more than 1.75 % of anhydrous sulphuric acid (SO_3) nor more than 4 % of magnesia (MgO).

0.8. The specific gravity of the cement after ignition to a low red heat shall not be less than 3.10; and the cement shall not show a loss in weight on ignition of more than 4 %.

0.9. The standard sand used in the tests shall be natural sand from Ottawa, Ill., screened to pass a No. 20 standard sieve of 400 meshes per square inch and be retained on a No. 30 standard sieve of 900 meshes per square inch.

Water for Concrete

Water for concrete must be clean and pure, free from silt or animal or vegetable wastes; it must not be oily or show either a strong acid or alkaline reaction when tested with litmus paper. (It ought to be fit to drink. A practical test is to require the contractor to drink it instead of beer. This last clause is suggested by the Prohibition element.)

Fine Aggregate for Concrete

0.10. Fine aggregate shall consist of sand free from organic matter; that which shows a coating on the grains shall not be used until satisfactorily washed. Sand shall be classified as No. 1, No. 2 and No. 3, and Grout Sand.

No. 1 Sand

0.11. No. 1 sand shall be of the following gradation: 100 % shall pass a ¼-inch screen, not more than 20 % shall pass a No. 50 sieve; and not more than 6 % shall pass a No. 100 sieve. In special cases where more than 20 % of a sand passes a No. 50 sieve and the sand is well graded to give a low percentage of voids, written permission for use of the sand may be given by the first deputy commissioner. Sand may be rejected for this class if it contains more than 5 % of loam and silt.

0.12. Mortar in the proportion of 1 part of cement to 3 parts of the sand

to be tested shall develop a compressive strength at least equal to the strength of a similar mortar of the same age composed of the same cement and standard Ottawa sand.

No. 2 Sand

0.13. No. 2 sand shall fulfill all of the requirements for No. 1 sand except that restrictions on the percentage that will pass a No. 50 and No. 100 sieve shall be governed by the compressive strength of the mortar. The compressive strength of the mortar shall be at least equal to that obtained with the standard Ottawa sand.

No. 3 Sand

0.14. Sand may be rejected for this class if it contains more than 8 % of loam and silt. Mortar in the proportion of 1 part of cement to 3 parts of the sand when tested shall develop a compressive strength of at least 80 % of the strength of a similar mortar of the same age composed of the same cement and standard Ottawa sand.

Screenings

0.15. Screenings shall not be used as fine aggregate except to the extent and under the restrictions given below. The division engineer shall submit samples to the Bureau of Tests; they must pass the required tests; their use must be approved in writing by the First Deputy Commissioner.

0.16. Screenings may be substituted for a portion of the No. 1, 2 and 3 sand under the following conditions:

The screenings shall be free from dust coating and other dirt. One hundred per cent. shall pass a ¼ inch screen and not more than 6 % shall pass a No. 100 sieve. The compressive strength of a mortar in which the screenings and sand are in the proportions intended for use, shall be at least equal to the standard strength obtained with sand of the given class.

Grout Sand

0.17. Grout sand shall be a sand of which 100 % passes a No. 20 sieve, and not over 30 % a No. 100 sieve. Sand may be rejected for this class if it contains more than 5 % of loam and silt. The grains shall be free from coating.

Mortar in the proportion of 1 part of cement to 3 parts of the sand shall develop a compressive strength of at least 40 % of the strength of a similar mortar of the same age composed of the same cement and standard Ottawa sand.

Cushion Sand

0.18. Cushion sand shall be a sand of which 100 % passes a No. 6 sieve and 90 % passes a No. 20 sieve; an excessively fine sand will not be accepted in this class. Sand may be rejected for this class if it contains more than 10 % of loam and silt.

Coarse Aggregate for Concrete

Stone

0.19. Crushed stone for concrete shall be of hard, durable stone, tested by the Bureau of Tests and satisfactory to the engineer. Stone for concrete shall be of an approved kind and quality of rock and shall be free, before being crushed, from soil, mud and dust. Crushed stone for first-class concrete shall be in fragments that will pass through a 1¼-inch circular hole and that will not pass through a ¼-inch square hole. Crushed stone for second-class or third-class concrete shall be in fragments that will pass through a 2¼-inch circular hole and that will not pass through a ¼-inch square hole.

Gravel

0.20. Gravel shall not be used in concrete except when it has been submitted by the Division Engineer to the Bureau of Tests, has been approved by the Bureau of Tests, and its use has been approved by the First Deputy Commissioner in writing—and then only under the restrictions given below.

0.21. Gravel for use in concrete pavement and first-class concrete shall be composed of hard, durable stone absolutely clean and free from coating. No gravel will be accepted that contains any disintegrated or soft stone or shale. Gravel containing any flat stone shall not be permitted. Gravel for use in second and third class concrete shall be composed of a sound, durable stone. It shall be clean and free from coating. It shall not contain more than 10% of soft stone or shale. Gravel containing a larger percentage of flat stone shall not be permitted.

0.22. Gravel for first-class concrete shall be in particles that will pass through a 1¼-inch circular hole and that will not pass through a ¼-inch square hole. Gravel for second and third-class concrete shall be in particles that will pass through a 2¼-inch circular hole and that will not pass through a ¼-inch square hole.

0.23. Gravel mixed with mud, clay, dirt or quicksand shall be washed to the satisfaction of the engineer. Run of bank gravel shall not be permitted. All gravel shall be properly screened and the coarse and fine aggregate regularly proportioned thereafter.

0.24. All coarse aggregate used for concrete shall be uniformly graded from the minimum to the maximum sizes of stone or gravel specified above for the several types of concrete, thus producing an aggregate in which the voids will be a minimum.

Stone, Gravel, etc., for Pavements

0.25. The sizes of all stone, gravel, etc., used under these specifications shall be determined by the size of screen aperture through which the stone will pass when revolved in a rotary screen. They shall be designated as follows:

Diameter of Aperture Min.	Max.	
	¼-inch square	Screenings
¼-inch square	⅝-inch circular	No. 1
⅝-inch circular	1¼-inch circular	No. 2
1¼-inch circular	2¾-inch circular	No. 3
2¾-inch circular	3¾-inch circular	No. 4

0.26. Gravel shall consist of clean, sound, tough hard stone. Gravel shall be separated into five grades or sizes by means of a rotary screen having openings as specified above for broken stone. All the general specifications given below relating to broken stone shall apply to gravel, excepting that gravel may contain not more than 5% of loam, but must otherwise be free from dirt or foreign matter and shall be washed if so directed by the engineer.

0.27. Broken slag shall be approved acid slag, clean, sound, tough, hard, sharp angled and weigh not less than 1800 pounds per cubic yard. If specified for use, it shall conform to all the general requirements for broken stone as specified below.

0.28. Broken stone shall be clean and sharp angled, shall pass the standard tests for abrasion and toughness as adopted by the American Society for Testing Materials, and shall be approved by the Bureau of Tests and acceptable to the engineer before being used.

0.29. Field stones, boulders, or fence stones which are crushed for macadam purposes shall be 6 or more inches in diameter, if consisting of rounded cobbles. If of the flat variety, the minimum thickness shall be 2 inches, which latter requirement will also apply to laminated quarry stone.

0.30. If after trial it is found that partially developed quarries, ledges or other sources of supply do not furnish a uniform product, or if, for any reason, the product from any source, at any time, proves to be unsatisfactory to the engineer, said engineer may require the contractor to furnish stone from other sources of supply, and the contractor shall have no claim for increased payment on account of such requirement.

0.31. The contractor shall furnish one or more stone crushing plants of type, composition, and capacity satisfactory to the engineer. The rotary screens shall be provided with openings of size and shape given under "Stone Sizes," unless otherwise ordered by the engineer. They must be of sufficient length and have the proper pitch and speed of revolution to accomplish complete separation of the sizes noted.

All crushing plants installed on the work shall be fitted up with a tailing chute so that no stone will reach the bins other than that which passes through the proper screen.

0.32. All stone must be of the required size when placed in the roadway, and no breaking up of stone by hammers or otherwise will be permitted after the stone has been placed in the work.

0.33. In no case shall any constituent of macadam pavement be dumped into place in mass; the final placing shall be by shovel or by thin spreading such that no appreciable fall occurs.

Filler or Binder.—The filler for the bottom course shall be clean, coarse sand or stone screenings supplemented by product of the crusher not otherwise used in top or bottom courses. The filler and wearing surface for the top course shall be of top course stone screenings and when bituminous binder is used screenings must be dry, free from dust, and not larger than will pass a ⅝-inch screen.

BITUMINOUS MATERIALS

Methods of Testing Bituminous Materials in the Laboratory of the Commission

Preparing Laboratory Samples.—Each laboratory sample is usually composed of several samples that have been taken to represent one lot of material. The material in the separate samples is examined, and, if uniform in appearance, equal amounts are taken from each and thoroughly blended to form a sample of about one-half pint on which the complete analysis is run.

In case of mineral bitumen, the sample received is thrown on a large piece of paper, pieces which are evidently foreign to the material are rejected, and the whole "quartered down" to a sample of about 300 grams. This is ground in a mortar and the analysis run on this part of the original sample.

Water Present.—The presence of water in an oil, asphalt, or tar is determined by putting about 40 grams of the material into a deep, seamless 3-ounce tin box, a thermometer being suspended in the material. This is then heated to about 230°F. without stirring. If water is present, even in very small quantities, the material will froth when heated to about 212°F. The per cent. of water present is determined by heating 20 grams of the material in a 2-ounce seamless tin box in an oven maintained at a temperature of 212°F. for an hour. The per cent. of water in mineral bitumen is determined in a similar manner. The loss in weight, while not absolutely correct, is considered as moisture.

Homogeneity.—The homogeneity of the mixture is shown by its general appearance at a temperature of 77°F. when in a melted condition and when examined under the microscope.

Gravity.—The gravity is determined by taking a small test tube about ⅝ of an inch by 3¼ inches, which is accurately weighed (weight A). The tube is then filled with distilled water at 77°F. and weighed (weight B). To get the gravity of the oil, asphalt, or tar the tube is filled with the material, cooled to a temperature of 77°F., cut off level with the top, and weighed (weight C). The gravity is determined as follows: $\frac{C - A}{B - A}$ = gravity.

Penetration.—The penetration test is made by putting the material to be tested in a 3-ounce deep, seamless tin box. Melting the material at the lowest possible temperature, cooling in air and then placing the material in a bath, for one hour, maintained at the temperature at which the test is to be made. The penetration is the distance expressed in hundredths of a centimeter which a standard needle under a stated load, and at a stated temperature, will penetrate into the material. The factors usually employed are a No. 2 sewing needle, loaded with 100 grams, applied for five seconds at a temperature of 77°F.

Residue Having a Penetration of 10 Millimeters.—This test is made as follows: 50 grams of the oil are placed in a 3-ounce deep, seamless tin box, the box placed in a sand bath and heated over a Bunsen Burner. A ther-

mometer is suspended in the oil, the bulb not touching the bottom of the box. The temperature of the oil is kept at from 480°F. to 500°F. and the oil is stirred from time to time with the thermometer to prevent overheating in any part. Depending upon the nature of the oil, as usually indicated by its flash, consistency at 77°F. and gravity, the operator can tell about what per cent. it will be necessary to evaporate before cooling and taking a penetration as described under the test for penetration. It is sometimes necessary to make several trials before the desired result is obtained. When the required penetration is reached, the residue left from evaporation is weighed and its per cent. of the original sample taken is computed.

Ductility.—The ductility of an asphalt cement or bitumen is determined by the distance in centimeters that a briquette of the material will draw out before breaking. The briquette of the asphalt cement is molded in a Dow briquette mold having a central cross-section 1 centimeter square a 2-square centimeter cross-section at mouth of clips, and a distance of 3 centimeters between clips. The molding of the briquette is done as follows: The mold is placed on a brass plate. To prevent the asphalt cement from adhering to this plate and the inner sides of the two pieces of the mold, they shall be well amalgamated. The asphalt cement to be tested is poured into the mold while in a molten state, a slight excess being added to allow for shrinkage on cooling. After the asphalt cement is nearly cooled, the briquette is smoothed off level by means of a hot spatula. When it is thoroughly cooled to the temperature at which it is desired to make the test, the clamp and the two side-pieces are removed, leaving the briquette of asphalt cement held at each end by the ends of the mold which serve as clips. The test is made by pulling the two clips apart at a uniform rate of 5 centimeters per minute by means of hooks inserted in the eyes, until rupture occurs. The briquette is kept in water at 77°F. for at least 30 minutes before testing, and the test is performed while the briquette is so immersed in the water at the above temperature, and at no time is the temperature of the water allowed to vary more than half a degree from the standard temperature.

Toughness.—The bitumen is heated until liquid; it is then poured into an amalgamated brass mold of such shape as to give a cylinder of the bitumen 1¾ inches in height by 1¾ inches in diameter. After cooling, the mold is removed and the cylinder of bitumen is placed in a mixture of finely crushed ice and water, giving a temperature of zero degrees centigrade. After remaining in the freezing mixture for about three hours the cylinders are broken in a Page impact machine (the standard machine of the American Society for Testing Materials for determining the toughness of macadam stone). When the cylinder to be broken is placed in the impact machine a piece of linen cloth about one inch square is placed on the end on which the plunger rests. This prevents the plunger from sticking to the bitumen and makes it easier to clean the machine. In making the test, the first drop of the hammer is from a height of five centimeters, and for each succeeding blow the height of the drop is increased five centimeters. The height from which the hammer falls when rupture occurs is given as the toughness of the material.

Melting Point of Bitumen.—The melting or softening point of bitumen is determined by filling a ring ⅝ inch in diameter by ¼ inch in depth, with the bitumen to be tested. After cooling, the bitumen is cut off level with the top of the ring. The ring containing the bitumen is placed in water at 41°F. for 20 minutes before making the test. In performing the test the ring is put in a support so placed that the bottom of the ring is 1 inch above the bottom of an 800 cc. beaker. On the center of the bitumen in the ring, is placed a ⅜-inch steel ball, a thermometer being placed with its bulb on a level with the ring containing the bitumen. The beaker is nearly filled with water at a temperature of 41°F. and the temperature raised at the rate of 8°F. to 10°F. per minute. The temperature recorded by the thermometer at the time the ball touches the bottom of the beaker is taken as the melting point of the bitumen.

Evaporation.—Fifty grams of the material are weighed into a flat-bottomed dish 2 3/16 in. in diameter by 1⅜ in. in depth. This is placed in an oven maintained at a uniform temperature of 325°F. for a period of five hours. At the end of this period the loss in weight or per cent. of loss is found by reweighing.

Flash.—About 40 grams of the material to be tested are placed in a 3-ounce deep, seamless tin box. The box containing the material is placed

on a sand bath over a Bunsen Burner, the bulb of a thermometer being placed in the material, but so adjusted as not to touch the bottom of the box. The flame of the Bunsen burner is so adjusted that the temperature of the material being tested is raised at the rate of 10°F. to 15°F. per minute. As soon as vapors are seen coming off, the small flame from a capillary tube is passed over the center of the liquid and about 1/4 inch above it, and repeated for about every 5°F. rise in temperature until the slight explosion indicates the flash-point is reached. The temperature at this point is recorded as the open flash-point of the material being tested.

Total Bitumen.—The solubility in $C\ S_2$ is found by weighing approximately 1 gram of the material into an Erlenmeyer flask, adding 50 cc. of $C\ S_2$ and allowing the solvent to act 12 hours at laboratory temperature, care being taken to break up all lumps before filtering. The filtration is made through a C. S. & S. 9-centimeter filter paper No. 589. The papers are first dried, and weighed immediately before using. The filtration is made in a valve funnel, a watch glass being placed on the funnel to prevent evaporation of the solvent. After washing until washings come clean, the filter and residue are placed in an oven at 212°F. for 30 minutes, cooled in a desiccator and weighed. The difference in weight gives the amount of material insoluble in $C\ S_2$ from which the per cent. of soluble bitumen is computed.

The total bitumen in mineral bitumen is determined by weighing about 25 grams of the dried material into a dried and weighed C. S. & S. extraction cartridge and extracting in a continuous extraction apparatus, using $C\ S_2$ for a solvent; drying and weighing after extraction is completed. The loss gives the amount of bitumen soluble in $C\ S_2$.

Carbon Tetrachloride Solubility.—This test is made in the same manner as determining the bitumen soluble $C\ S_2$, except that $C\ C\ l_4$ is used as solvent.

Naphtha Solubility. The amount of material soluble in 76° naphtha (boiling point 140°F. to 190°F.) is found by the same method that is used in getting the amount soluble in $C\ S_2$, except that naphtha is used for a solvent in place of $C\ S_2$. The character of the filtrate is determined by placing about 10 cc. of the filtrate in the tin covers of the 2-ounce boxes used in making the heating tests and allowing the filtrate to evaporate. The residue is noted to be sticky or oily by rubbing between the fingers.

Water Soluble Materials.—Water soluble materials in tar are determined by weighing about 2 grams into a casserole, adding 50 cc. of distilled water, and boiling for 1 hour. The solution is then filtered into a weighted porcelain evaporating dish, using hot distilled water for a wash and evaporated to dryness on a steam bath. The weight at the evaporating dish and contents after drying to a constant weight at 212°F., less the weight of the dish itself, gives the amount of water soluble materials in the tar, from which the per cent. may be calculated.

Free Carbon.—The free carbon in tar is determined by extraction at room temperature with $C\ S_2$. In extraction $C\ S_2$ is used in the same manner as making the determination for the amount of bitumen soluble in $C\ S_2$ in asphalts. Determination as to whether extraction is complete is made by placing some of the carbon on white porcelain, moistening it with $C\ S_2$, and if the porcelain is stained the extraction is not complete, and the carbon requires more washing.

Paraffine.—Fifty grams of the material are placed in a half-pint retort, E. & A. No. 4521, fitted with a tee condenser. To the 20-inch iron delivery tube of the retort is attached a 10-inch glass tube, and between the cover and the retort is placed a paper gasket cut from heavy wrapping-paper. The material is rapidly distilled to a dry coke from which no further distillate can be obtained, not over 25 minutes being allowed from the time of placing flame under retort until distillation ceases. About 5 grams of the distillate are taken if the materials contain 2 per cent. or less of paraffine and about 3 grams if the material contains over 2 per cent. of paraffine. This amount of distillate is dissolved in 25 cc. of Squibbs Absolute Ether in a 2-ounce glass flask, after which 25 cc. of Squibbs Absolute Alcohol are added. A one-to-one wash of 25 cc. each of similar ether and alcohol is made up, and the solution of oil and the wash are then frozen separately for 40 minutes in a salt and ice mixture, giving a temperature of 0°F. The precipitate is filtered quickly by means of a suction pump by using a No. 575 C. S. & S. 9-centimeter hardened filter-paper; the paper being placed in a funnel packed in a freezing mixture of salt and ice. The paraffine caught on the filter-paper is washed with the cool one-to-one wash until the paraffine is white. The paraffine is then scraped into a weighted crystallizing dish and main-

tained at a temperature of 212°F. until a constant weight is obtained, after which it is weighed and the percentage of paraffine in the original material is computed by dividing the weight of the paraffine obtained by the number of grams of distillate taken for freezing, and multiply this result by the percentage distilled from the original sample (*i.e.*, by 100 per cent. less weight of coke expressed in percentage). The paraffine so determined to have a melting point of at least 120°F.

The melting-point of paraffine is determined by covering the bulb of a thermometer with the paraffine; suspending the thermometer in a beaker of water at 65°F., and heating the water at the rate of 8° to 10°F. per minute. The temperature recorded by the thermometer at the time the paraffine melts from the bulb is taken as the melting-point of the paraffine.

Distillation of Tar.—The distillation test of tar is made by measuring 100 cubic centimeters of the tar into a 250 cc. Engler distilling flask with delivery tube at the middle of the neck. The thermometer is so placed that the mercury bulb is opposite the outlet of the flask. The thermometer used to have a nitrogen chamber to insure accurate reading at high temperatures. The flame is so regulated that approximately 1 cc. of distillate is caught per minute. The distillation is made continuous.

The following fractions should be reported:

Start of distillation to 110°C.
110°C. " 170°C.
170°C. " 235°C.
235°C. " 270°C.
270°C. " 300°C.
Residue (pitch)

Fixed Carbon and Mineral Matter.—The fixed carbon is determined by weighing approximately 1 gram of the material into a weighed platinum crucible with a tightly fitting cover. The crucible, with its cover in place, is then placed about 4 inches over a freely burning Bunsen burner so as to be completely enveloped in the flame and exposed to the full heat of the burner for about 3 minutes or until the top of the crucible cover is burned free from the carbon; the under side of the cover being covered with the carbon. The flame is then withdrawn, the crucible cooled and weighed. The weight after burning, less the weight of the crucible, gives the amount of fixed carbon plus the mineral matter. The fixed carbon is then burned off in the open crucible until a constant weight is obtained; the crucible cooled and weighed. This weight is the crucible plus the mineral matter. The mineral matter subtracted from the combined weight of fixed carbon and mineral matter gives the fixed carbon.

Items 64 to 74 Inclusive—Bituminous Materials

64.1. Under items 64 to 74 inclusive the Contractor shall furnish and deliver on the work at such points as the Engineer may direct, bituminous material of the kind shown on the proposal sheet as to be furnished under its respective item.

64.2. Bituminous material furnished shall be of approved quality and shall meet the requirements specified below for the kind of material furnished, and for any contract, the material furnished shall be of one brand and shall show a uniform test unless special permission is given to furnish other brands of material.

64.3. The quantity to be paid for under this item shall be the number of gallons delivered on the work, unless the material is to be incorporated in the work by the same Contractor, and under the same contract.

If the material is to be incorporated in the work by the same Contractor, and under the same contract, the quantity to be paid for under this item shall be the number of gallons incorporated in the work under directions of the Engineer.

Bituminous material that has been rendered unfit for use by overheating or by long-continued heating, shall not be paid for. For purposes of measurement, a gallon shall be a volume of 231 cubic inches and measurement shall be based on the volume of the bituminous material of a temperature of 60 degrees Fahrenheit.

The price bid when the material is not to be incorporated in the work under this contract, shall include the furnishing of the material along the road as directed by the Engineer. Any material wasted through careless handling will not be paid for.

The price bid shall include the furnishing of the bituminous material alongside the road at places designated by the Engineer. Where the material delivered is to be incorporated into the work under this contract, the cost of manipulating and incorporating this material shall be included in the price bid for the top course of the pavement being constructed.

Item 64—Specification for Bituminous Material A

MIXING METHOD (TYPE 1) (OPEN MIX)

This bituminous material shall have the following characteristics:

(1) It shall be free from water.

(2) The various hydrocarbons composing it shall be present in a homogeneous solution.

(3) It shall have a specific gravity at 77 degrees Fahrenheit of not less than 0.97.

(4) The penetration shall be between 8 and 12 millimeters when tested for 5 seconds at 77 degrees Fahrenheit with a No. 2 needle, weighted with 100 grams.

(5) Fifty grams of it upon being maintained at a uniform temperature of 325 degrees Fahrenheit for 5 hours in a cylindrical vessel $5\frac{1}{2}$ centimeters in diameter by $3\frac{1}{2}$ centimeters high shall not lose more than 4 per centum in weight. The penetration (5 seconds, 77 degrees Fahrenheit, No. 2 needle, 100 grams weight) of this residue shall be at least 50 per centum of the original penetration.

(6) Its solubility at air temperature in chemically pure carbon disulphide for the following named materials, or materials similar thereto, shall be at least 99.5 per centum for pure bitumen products, 96 per centum for Bermudez products, 81 per centum for Cuban products and 66 per centum for Trinidad products.

(7) The solubility of the bitumen at air temperature, in 76 degrees Beaumé paraffine petroleum naphtha distilling between 140 degrees and 190 degrees Fahrenheit, shall be between 68 and 88 per centum.

(8) The bitumen shall show between 8 and 17 per centum fixed carbon.

(9) It shall show an open flash point not less than 375 degrees Fahrenheit.

(10) It shall not contain more than 4.7 per centum paraffine scale.

(11) It shall show a toughness at 32 degrees Fahrenheit not less than 10 centimeters. Toughness is determined by breaking a cylinder of the material $1\frac{3}{4}$ inches in diameter by $1\frac{3}{4}$ inches in height in a Page impact machine. (American Society of Testing Materials, August 15, 1908). The first drop of the hammer is from a height of 5 centimeters and each succeeding blow is increased by 5 centimeters.

(12) It shall have a ductility at 77 degrees Fahrenheit of not less than 25 centimeters (Dow mould).

(13) All bituminous material A. will be sampled by an Engineer of the Department of Highways and samples sent to the Bureau of Tests, Albany, N. Y.

Item 65—Specification for Bituminous Material A

MIXING METHOD (TYPE NO. 2) (TOPEKA MIX)

This bituminous material shall have the following characteristics:

(1) It shall be free from water.

(2) The various hydrocarbons composing it shall be present in a homogeneous solution.

(3) It shall have a specific gravity at 77 degrees Fahrenheit of not less than 0.97.

(4) The penetration shall be between 6 and 8 millimeters when tested for 5 seconds at 77 degrees Fahrenheit with a No. 2 needle, weighted with 100 grams.

(5) Fifty grams of it being upon maintained at a uniform temperature of 325 degrees Fahrenheit for 5 hours in a cylindrical vessel, $5\frac{1}{2}$ centimeters in diameter by $3\frac{1}{2}$ centimeters high shall not lose more than 4 per centum in weight. The penetration (5 seconds, 77 degrees Fahrenheit, No. 2 needle, 100 grams weight) of this residue shall be at least 50 per centum of the original penetration.

(6) Its solubility at air temperature in chemically pure carbon disulphide

for the following named materials, or materials similar thereto, shall be at least 99.5 per centum for pure bitumen products, 96 per centum for Bermudez products, 81 per centum for Cuban products and 66 per centum for Trinidad products.

(7) The solubility of the bitumen at air temperature, in 76 degrees Beaumé paraffine petroleum naphtha distilling between 140 degrees and 190 degrees Fahrenheit shall be between 68 and 88 per centum.

(8) The bitumen shall show between 8 and 17 per centum fixed carbon.

(9) It shall show an open flash point not less than 375 degrees Fahrenheit.

(10) It shall not contain more than 4.7 per centum paraffine scale.

(11) It shall show a toughness at 32 degrees Fahrenheit not less than 5 centimeters. Toughness is determined by breaking a cylinder of the material 1¾ inches in diameter by 1¾ inches in height in a Page impact machine. (American Society of Testing Materials, August 15, 1908.) The first drop of the hammer is from a height of 5 centimeters and each succeeding blow is increased by 5 centimeters.

(12) It shall have a ductility at 77 degrees Fahrenheit of not less than 25 centimeters (Dow mould).

(13) All bituminous material A. will be sampled by an Engineer of the Department of Highways and samples sent to the Bureau of Tests, Albany, N. Y.

Item 66—Specification for Bituminous Material A

Penetration Method

This bituminous material shall have the following characteristics:

(1) It shall be free from water.

(2) The various hydrocarbons composing it shall be present in a homogeneous solution.

(3) It shall have a specific gravity at 77 degrees Fahrenheit of not less than 0.97.

(4) The penetration shall be between 14 and 19 millimeters when tested for 5 seconds at 77 degrees Fahrenheit with a No. 2 needle, weighted with 100 grams.

(5) Fifty grams of it upon being maintained at a uniform temperature of 325 degrees Fahrenheit for 5 hours in a cylindrical vessel 5½ centimeters in diameter by 3½ centimeters high shall not lose more than 5 per centum in weight. The penetration (5 seconds, 77 degrees Fahrenheit, No. 2 needle, 100 grams weight) of this residue shall be at least 50 per centum of the original penetration.

(6) Its solubility at air temperature in chemically pure carbon disulphide for the following named materials, or materials similar thereto, shall be at least 99.5 per centum for pure bitumen products, 96 per centum for Bermudez products, 81 per centum for Cuban products and 66 per centum for Trinidad products.

(7) The solubility of the bitumen at air temperature, in 76 degrees Beaumé paraffine petroleum naphtha distilling between 140 degrees and 190 degrees Fahrenheit shall be between 70 and 88 per centum.

(8) The bitumen shall show between 8 and 16 per centum fixed carbon.

(9) It shall show an open flash point not less than 375 degrees Fahrenheit.

(10) It shall not contain more than 4.7 per centum paraffine scale.

(11) It shall show a toughness at 32 degrees Fahrenheit not less than 15 centimeters. Toughness is determined by breaking a cylinder of the material 1¾ inches in diameter by 1¾ inches in height, in a Page impact machine. (American Society of Testing Materials, August 15, 1908.) The first drop of the hammer is from a height of 5 centimeters and each succeeding blow is increased by 5 centimeters.

(12) It shall have a ductility at 77 degrees Fahrenheit of not less than 40 centimeters (Dow mould).

(13) All bituminous material A. will be sampled by an Engineer of the Department of Highways, and samples sent to the Bureau of Tests Albany, N. Y.

Item 67—Specification for Bituminous Material H. O. (Surface application)

This bituminous material shall have the following characteristics:

(1) It shall be free from water.

(2) The various hydrocarbons composing it shall be present in a homogeneous so'ution.

(3) It shall have a spec-fic gravity at 77 degrees Fahrenheit of not less than 0.96.

(4) When evaporated in the open air at a temperature not exceeding 500 degrees Fahrenheit until the residue remaining has a penetration (5 seconds, 77 degrees Fahrenheit, No. 2 needle, 100 grams weight) of 10 millimeters the amount of such residue shall not be less than 85 per centum nor more than 95 per centum of the original oil. At a temperature of 77 degrees Fahrenheit such residue shall have a ductility of at least 25 centimeters (Dow mould).

(5) Fifty grams of it upon being maintained at a uniform temperature of 325 degrees Fahrenheit for five hours, in a cylindrical vessel 5½ centimeters in diameter by 3½ centimeters high, shall not lose more than 10 per centum in weight.

(6) It shall be soluble in chemically pure carbon disulphide at air temperature to the extent of at least 99.5 per centum.

(7) It shall be soluble at air temperature in 76 degrees Beaumé paraffine petroleum naphtha distilling between 140 degrees and 190 degrees Fahrenheit to the extent of not less than 75 per centum and not more than 90 per centum.

(8) It shall show between 6 and 14 per centum of fixed carbon.

(9) It shall show an open flash point of not less than 325 degrees Fahrenheit.

(10) It shall not contain more than 4.7 per centum paraffine scale.

(11) It shall show a toughness at 32 degrees Fahrenheit not less than 20 centimeters. Toughness is determined by breaking a cylinder of the material 1¾ inches in diameter by 1¾ inches in height in a Page impact machine. (American Society of Testing Materials, August 15, 1908.) The first drop of the hammer is from a height of 5 centimeters and each succeeding blow is increased by 5 centimeters.

(12) All bituminous material H. O. will be sampled by an Engineer of the Department of Highways, and samples sent to the Bureau of Tests, Albany, N. Y.

Item 68—Specification for Bituminous Material C. O. (Surface application)

This bituminous material shall have the following characteristics:

(1) It shall be free from water.

(2) The various hydrocarbons composing it shall be present in a homogeneous solution.

(3) It shall have a specific gravity at 77 degrees Fahrenheit of not less than 0.93.

(4) When evaporated in the open air at a temperature not exceeding 500 degrees Fahrenheit until the residue remaining has a penetration (5 seconds, 77 degrees Fahrenheit, No. 2 needle, 100 grams weight) of 10 millimeters the amount of residue shall not be less than 50 per centum nor more than 65 per centum of the original oil. At a temperature of 77 degrees Fahrenheit such residue shall have a ductility of at least 25 centimeters (Dow mould).

(5) Fifty grams of it upon being maintained at a uniform temperature of 325 degrees Fahrenheit for five hours, in a cylindrical vessel 5½ centimeters in diameter by 3½ centimeters high, shall not lose more than 30 per centum in weight.

(6) It shall be soluble in chemically pure carbon disulphide at air temperature to the extent of at least 99.5 per centum.

(7) It shall be soluble at air temperatnre in 76 degrees Beaumé paraffine petroleum naphtha distilling between 140 and 190 degrees Fahrenheit to the extent of not less than 80 per centum and not more than 95 per centum.

(8) It shall not show more than 10 per centum fixed carbon.

(9) It shall show an open flash point of not less than 125 degrees Fahrenheit.

(10) It shall not contain more than 4.0 per centum paraffine scale.

(11) All bituminous material C. O. will be sampled by an Engineer of the Department of Highways, and samples sent to the Bureau of Tests, Albany, N. Y.

Item 69—Specification for Bituminous Material T

HIGH CARBON—BINDER FOR BITUMINOUS MACADAM

This bituminous material shall have the following characteristics:

(1) It shall be free from water.

(2) It shall be uniform in character, appearance, and viscosity.

(3) It shall have a specific gravity of not less than 1.20 at 25 degrees centigrade.

(4) It shall contain not more than 25 per centum nor less than 12 per centum of free carbon.

(5) When distilled by the method of the American Society for Testing Materials, it shall contain no body that distils at a lower temperature than 170 degrees Centigrade; not over 3 per centum shall distil below 235 degrees Centigrade; not over 12 per centum shall distil below 270 degrees Centigrade, and not over 16 per centum shall distil below 300 degrees Centigrade. The specific gravity of the entire distillate shall not be less than 1.03 at 25 degrees Centigrade. The residue from the foregoing distillation shall have a melting point not greater than 75 degrees Centigrade ball and ring method.

(6) It shall have a melting point of not less than 27 degrees C., and not more than 34 degrees C., by ball and ring method.

(7) All bituminous material T. will be sampled by an Engineer of the Department of Highways and samples sent to the Bureau of Tests, Albany, N. Y.

Item 70—Specification for Bituminous Material T

HIGH CARBON—HOT APPLICATION, SURFACE APPLICATION

This bituminous material shall have the following characteristics:

(1) It shall be free from water.

(2) It shall be uniform in character, appearance and viscosity.

(3) It shall have a specific gravity not less than 1.19 at 25 degrees Centigrade.

(4) It shall contain not more than 22 per centum nor less than 10 per centum of free carbon.

(5) When distilled by the method of the American Society for Testing Materials, it shall contain no body that distils at a lower temperature than 170 degrees Centigrade, not over 10 per centum shall distil below 235 degrees Centigrade; not over 16 per centum shall distil below 270 degrees Centigrade and not over 20 per centum shall distil below 300 degrees Centigrade. The specific gravity of the entire distillate shall not be less than 1.03 at 25 degrees Centigrade. The residue from the foregoing distillation shall have a melting point not greater than 75 degrees Centigrade ball and ring method.

(6) It shall have a float test (New York Testing Laboratory method) at 100 degrees Centigrade between eighteen and twenty-eight seconds.

(7) All bituminous material T. will be sampled by an Engineer of the Department of Highways, and samples sent to the Bureau of Tests, Albany, N. Y.

Item 71—Specification for Bituminous Material T (Surface Treatment)

HIGH CARBON—COLD APPLICATION

This bituminous material shall have the following characteristics:

(1) It shall have a specific gravity of 1.14 to 1.18 at 25 degrees Centigrade.

(2) It shall contain not more than 12 per centum nor less than 4 per centum of free carbon.

(3) When distilled by the method of the American Society for Testing Materials, not over 5 per centum shall distil below 170 degrees Centigrade; not over 18 per centum shall distil below 235 degrees Centigrade; not over 25 per centum shall distil below 270 degrees Centigrade, and not over 32 per centum shall distil below 300 degrees Centigrade. The specific gravity of the entire distillate shall not be less than 1.01 at 25 degrees Centigrade. The residue from the foregoing distillation shall have a melting point not greater than 70 degrees Centigrade ball and ring method.

(4) The viscosity when tested by the standard Engler viscosimeter shall not be more than 125 seconds at 60 degrees Centigrade for the first 100 cubic centimeters.

(5) All bituminous material T. will be sampled by an Engineer of the Department of Highways, and samples sent to the Bureau of Tests, Albany, N. Y.

Item 72—Specification for Bituminous Material T (Bituminous Macadam)

LOW CARBON—BINDER

This bituminous material shall have the following characteristics:

(1) It shall be free from water.

(2) It shall be uniform in character, appearance and viscosity.

(3) It shall have a specific gravity not less than 1.16 at 25 degrees Centigrade.

(4) It shall contain not more than 5 per centum free carbon.

(5) When distilled by the method of the American Society for Testing Materials, it shall contain no body that distils at a lower temperature than 170 degrees Centigrade; not over 5 per centum shall distil below 235 degrees Centigrade; not over 15 per centum shall distil below 270 degrees Centigrade; not over 20 per centum shall distil below 300 degrees Centigrade. The residue from the foregoing distillation shall have a melting point not greater than 75 degrees Centigrade ball and ring method.

(6) It shall have a melting point of not less than 27 degrees C., and not more than 34 degrees C., by ball and ring method.

(7) All bituminous material T. will be sampled by an Engineer of the Department of Highways, and samples sent to the Bureau of Tests, Albany, N. Y.

Item 73—Specification for Bituminous Material T (Surface Treatment)

LOW CARBON—HOT APPLICATION

This bituminous material shall have the following characteristics:

(1) It shall be free from water.

(2) It shall be uniform in character, appearance and viscosity.

(3) It shall have a specific gravity of not less than 1.14 at 25 degrees Centigrade.

(4) It shall contain not more than 4 per centum of free carbon.

(5) When distilled by the method of the American Society for Testing Materials, not over 1 per centum shall distil below 170 degrees Centigrade; not over 12 per centum shall distil below 235 degrees Centigrade; not over 20 per centum shall distil below 270 degrees Centigrade, and not over 25 per centum shall distil below 300 degrees Centigrade. The residue from the foregoing distillation shall have a melting point not greater than 75 degrees Centigrade ball and ring method.

(6) It shall have a float test (New York Testing Laboratory method) at 100 degrees Centigrade between fifteen and twenty-five seconds.

(7) All bituminous material T. will be sampled by an Engineer of the Department of Highways, and samples sent to the Bureau of Tests, Albany, N. Y.

Item 74—Specification for Bituminous Material T (Surface Treatment)

LOW CARBON—COLD APPLICATION

This bituminous material shall have the following characteristics:

(1) It shall have a specific gravity of 1.10 to 1.13 at 25 degrees Centigrade.

(2) It shall contain not more than 2 per centum of free carbon.

(3) When distilled by the method of the American Society for Testing Materials, not over 5 per centum shall distil below 170 degrees Centigrade; not over 20 per centum shall distil below 235 degrees Centigrade; not over 28 per centum shall distil below 270 degrees Centigrade, and not over 35 per centum shall distil below 300 degrees Centigrade. The residue from the foregoing distillation shall have a melting point not greater than 70 degrees Centigrade ball and ring method.

(4) The viscosity when tested by the standard Engler viscosimeter shall not be more than 125 seconds at 60 degrees Centigrade for the first 100 cubic centimeters.

(5) All bituminous material T. will be sampled by an Engineer of the

Department of Highways, and samples sent to the Bureau of Tests, Albany, N. Y.

Bituminous Material for Mastic fillers of Block Pavements (see page 789).

BRICK

Paving brick shall be reasonably perfect in shape—shall be free from marked warping or distortion, and shall be uniform in size, so as to fit closely together and to make a smooth pavement. All brick shall be homogeneous in texture and free from laminations and seams. All brick shall be evenly burned and thoroughly vitrified.

Soft, brittle, cracked, or spalled brick, or brick kiln-marked to a height or depth of over 3/64 part of an inch will be rejected.

If brick have rounded corners, the radius shall not be greater than 1/8 part of an inch.

Brick must have not less than two nor more than four vertical lugs or projections not more than 1/2 inch wide, on one side of each brick, the total area of all lugs being not more than 3 square inches, so that when laid there shall be a separation between the bricks of at least 1/8 inch and not more than 1/4 inch. The imprint, or name of the brick, or maker, if used, shall be by means of recessed and not by raised letters. The two ends of the brick shall have a semi-circular groove, with a radius of not less than 1/8 of an inch and not more than 1/4 of an inch. Grooves shall be so located that when the brick is laid together the grooves shall match perfectly; grooves shall be horizontal when brick is laid in pavement.

All brick shall not be less than 3 1/4" × 3 3/4" × 8 1/2" nor more than 3 1/2" × 4" × 9" in size.

All brick shall be subject to tests for abrasion and impact, for absorption, according to the standard methods prescribed by the National Brick Manufacturers' Association, as follows:

THE RATTLER

The machine shall be of good mechanical construction, self-contained, and shall conform to the following details of material and dimensions, and shall consist of barrel, frame and driving mechanism as herein described.

THE BARREL

The barrel of the machine shall be made up of the heads, headliners and staves.

The heads shall be cast with trunnions in one piece. The trunnion bearings shall not be less than two and one-half (2 1/2) inches in diameter or less than six (6) inches in length.

The heads shall not be less than three-fourths (3/4) inch thick nor more than seven-eighths (7/8) inch. In outline they shall be a regular fourteen-sided (14) polygon inscribed in a circle twenty-eight and three-eighths (28 3/8) inches in diameter. The heads shall be provided with flanges not less than three-fourths (3/4) inch thick and extending outward two and one-half (2 1/2) inches from the inside face of head to afford a means of fastening the staves. The flanges shall be slotted on the outer edge, so as to provide for two (2) three-fourths (3/4) inch bolts at each end of each stave, said slots to be thirteen-sixteenths (13/16) inch wide and two and three-fourths (2 3/4) inches center to center. Under each section of the flanges there shall be a brace three-eighths (3/8) inch thick and extending down the outside of the head not less than two (2) inches. Each slot shall be provided with recess for bolt head, which shall act to prevent the turning of the same. There shall be for each head a cast-iron headliner one (1) inch in thickness and conforming to the outline of the head, but inscribed in a circle twenty-eight and one-eighth (28 1/8) inches in diameter. This liner or wear plate shall be fastened to the head by seven (7) five-eighths (5/8) inch cap screws, through the head from the outside. These wear plates, whenever they become worn down one-half (1/2) inch below their initial surface level, at any point of their surface, must be replaced with new. The metal of which these wear plates are to be composed shall be what is known as hard machinery iron, and must contain not less than one (1) per cent. of combined carbon. The faces of the polygon must be smooth and give uniform bearing for the staves. To secure the desired uniform bearing the faces of the head may be ground or machined.

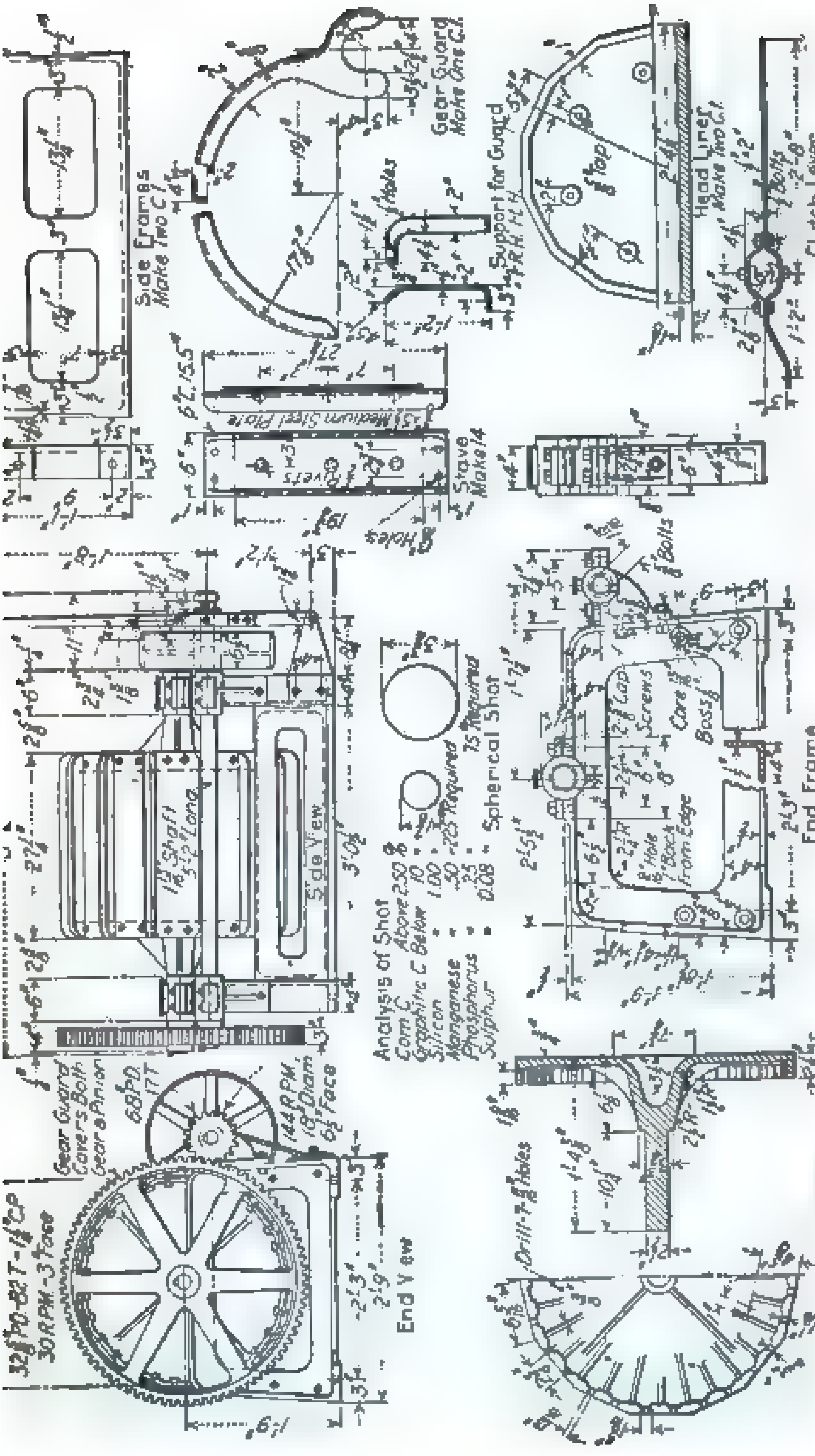

Side Frames
Make Two C.I.
Gear Guard
Make One C.I.
Support for Guard
Head Liner
Make Two C.I.
Clutch Lever
Make One
Stave
Make 14
Side View
Spherical Shot
End Frame
Make Two C.I.
End View
Trunion
Make Two C.I.

FIG. 147.

THE STAVES

The staves shall be made of six (6) inch medium steel structural channels twenty-seven and one-fourth (27¼) inches long and weighing fifteen and five-tenths (15.5) pounds per lineal foot.

The channels shall be drilled with holes thirteen-sixteenths (13/16) inch in diameter, two (2) in each end, for bolts to fasten same to head, the center line of the holes being one (1) inch from either end and one and three-eighths (1⅜) inches either way from the longitudinal center line.

The space between the staves will be determined by the accuracy of the heads, but must not exceed five-sixteenths (5/16) inch. The interior or flat side of each channel must be protected by a lining or wear plate three-eighths (⅜) inch thick by five and one-half (5½) inches wide by nineteen and three-fourths (19¾) inches long. The wear plate shall consist of medium steel plate, and shall be riveted to the channel by three (3) one-half (½) inch rivets, one of which shall be on the center line both ways and the other two on the longitudinal center line and spaced seven (7) inches from the center each way. The rivet holes shall be countersunk on the face of the wear plate and the rivets shall be driven hot and chipped off flush with the surface of the wear plate. These wear plates shall be inspected from time to time, and if found loose shall be at once reriveted, but no wear plate shall be replaced by a new one except as the whole set is changed. No set of wear plates shall be used for more than one hundred and fifty (150) tests under any circumstances. The record must show the date when each set of wear plates goes into service and the number of tests made upon each set.

The staves when bolted to the heads shall form a barrel twenty (20) inches long, inside measurement, between wear plates. The wear plates of the staves must be so placed as to drop between the wear plates of the heads. These staves shall be bolted tightly to the heads by four (4) three-fourths (¾) inch bolts, and each bolt shall be provided with lock nuts, and shall be inspected at not less frequent intervals than every fifth (5th) test and all nuts kept tight. A record shall be made after each such inspection, showing in what condition the bolts were found.

THE FRAME AND DRIVING MECHANISM

The barrel should be mounted on a cast-iron frame of sufficient strength and rigidity to support same without undue vibration. It should rest on a rigid foundation and be fastened to same by bolts at not less than four (4) points.

It should be driven by gearing whose ratio of driver to driven should not be less than one (1) to four (4). The counter shaft upon which the driving pinion is mounted should not be less than one and fifteen-sixteenths (1 15/16) inches in diameter, with bearings not less than six (6) inches in length and belt driven, and the pulley should not be less than eighteen (18) inches in diameter and six and one-half (6½) inches in face. A belt of six (6) inch double-strength leather, properly adjusted, so as to avoid unnecessary slipping, should be used.

(As a part of this publication will be found a complete working drawing of a machine which will meet the above specifications and requirements.)

THE ABRASIVE CHARGE

(*a*) The abrasive charge shall consist of two sizes of cast-iron spheres. The larger size shall be three and seventy-five-hundredths (3.75) inches in diameter when new and shall weigh when new approximately seven and five-tenths (7.5) pounds (3.40 kilos) each. Ten shall be used.

These shall be weighed separately after each ten (10) tests, and if the weight of any large shot falls to seven (7) pounds (3.175 kilos) it shall be discarded and a new one substituted; provided, however, that all of the large shot shall not be discarded and substituted by new ones at any single time, and that so far as possible the large shots shall compose a graduated series in various stages of wear.

The smaller size spheres shall be when new one and eight hundred seventy-five-thousandths (1.875) inches in diameter and shall weigh not to exceed

ty-five-hundredths (0.95) pounds (0.430 kilos) each. Of these spheres many shall be used as will bring the collective weight of the large and ll spheres most nearly to three hundred (300) pounds, provided that mall sphere shall be retained in use after it has been worn down so that ill pass a circular hole one and seventy-five-hundredths (1.75) inches in neter, drilled in a cast-iron plate one-fourth (¼) inch in thickness or gh less than seventy-five-hundredths (0.75) pounds (or 0.34 kilos). ther, the small spheres shall be tested by passing them over such an plate drilled with such holes, or shall be weighed after every ten (10) s, and any which pass through or fall below specified weight, shall be aced by new spheres, and provided, further, that all of the small spheres l not be rejected and replaced by new ones at any one time, and that ar as possible the small spheres shall compose a graduated series in ous stages of wear. At any time that any sphere is found to be broken lefective it shall at once be replaced.

b) The iron composing these spheres shall have a chemical composition hin the following limits:

Combined carbon—Not less than 2.50 %.
Graphitic carbon—Not more than 0.10 %.
Silicon—Not more than 1 %.
Manganese—Not more than 0.50 %.
Phosphorus—Not more than 0.25 %.
Sulphur—Not more than 0.08 %.

For each new batch of spheres used the chemical analysis must be furnished the maker, or be obtained by the user, before introduction into the rge, and unless the analysis meets the above specifications, the batch spheres shall be rejected.

THE BRICK CHARGE

The number of brick per charge shall be ten (10) for all bricks of the so-led "block size" whose dimensions fall between from eight (8) to nine inches in length, three (3) and three and three-fourths (3¾) inches in adth and three and three-fourths (3¾) and four and one-fourth (4¼) hes in thickness. No block should be selected for test that would be ected by any other requirements for the specifications.

The brick shall be clean and dried for at least three (3) hours in a temrature of one hundred (100) degrees Fahr. before testing.

SPEED AND DURATION OF REVOLUTION

The rattler shall be rotated at a uniform rate of not less than twenty-ne and one-half (29½) nor more than thirty and one-half (30½) revolutions r minute, and eighteen hundred (1800) revolutions shall constitute the andard test.

A counting machine shall be attached to the rattler for counting the volutions. A margin of not to exceed ten (10) revolutions will be allowed r stopping. Only one (1) start and stop per test is regular and acceptable.

THE RESULTS

The loss shall be calculated in percentage of the original weight of the ied brick composing the charge. In weighing the rattled brick any ece weighing less than one (1) pound shall be rejected.

RECORDS

(a) The operator shall keep an official book, in which the alternate pages e perforated for removal. The record shall be kept in duplicate, by e of a carbon paper between the first and second sheets, and when all enies are made and calculations are completed the original record shall be moved and the carbon duplicate preserved in the book. All calculations ust be made in the space left for that purpose in the record blank, and the tual figures must appear. The record must bear its serial number and be

filled out completely for each test, and all data as to dates of inspection a weighing of shot and replacement of worn-out parts must be carefully ente so that the records remaining in the book, constitute a continuous one. event of further copies of a record being needed, they may be furnished separate sheets, but in no case shall the original carbon copy be removed f the record book.

REPORT OF

Standard Rattler Test of Paving Bricks

Identification Data Serial No. (

Name of the firm furnishing sample

Name of the firm manufacturing sample

Street or job which sample represents

Brands or marks on the brick

Quantity furnished Drying treatment

Date received Date tested

Length Breadth Thickness

Standardization Data

Number of charges tested since last inspection

Weight of Charge (After Standardization)	Condition of Locknuts on Staves	Condition of Scales
10 Large spheres		
Small spheres		
Total		

Number of charges tested since stave linings were renewed

Repairs (Note any repairs affecting the condition of the barrel)

Running Data

	Time Readings			Revolution Counter Readings	Running Notes, Stops, Etc.
	Hours	Minutes	Seconds		
Beginning of test . . .					
Final Reading					

Weights and Calculations

		Percentage Loss (Note.—The Calculation Must Appear)
Initial Weight of 10 Bricks		
Final Weight of Same		
Loss of Weight		

Number of broken bricks and remarks on same

I certify that the foregoing test was made under the specifications of and is a true record.

Signature of (Tester) ________________

Date Location of Laboratory

FIG. 148.

(*b*) The blank form upon which the record of all official brick tests i to be kept and reported is shown in Fig. 148.

Any brick which loses twenty-four (24) per cent. or more in the rattler, or in creases more than 3½ % in weight or less than ½ of 1 % in the absorptio test, will be rejected.

HILLSIDE BRICK

On grades of five (5 %) per cent. or over the engineer may, if he deems advisable for the traffic, order the contractor to use special form of brick suitable for steep grades.

Expansion Joint Paving Pitch.—This cushion shall be composed of heavy pitch or asphaltum composition, having a melting point of not less than 120° F. nor more than 140°F., filling the allotted space.

PREMOLDED EXPANSION JOINT

The expansion joints shall be composed of a high grade asphalt, that shall pass the following tests:

Specific gravity at 77°F., 0.98 to 1.05.
Melting point, ball and ring method, 220° to 250°F.
Loss on heating for 5 hours at 325°F., not over 1 %.
Bitumen soluble in carbon disulphide, at least 98.5 %.
Bitumen soluble in carbon tetrachloride, at least 99.8 %.
Bitumen soluble in 76° Beaumé naphtha, 50 to 75 %.
Penetration at 32° F. 200 grams, 1 min., at least 12.
Penetration at 77° F. 100 grams, 5 sec. between 15 and 35.
Penetration at 115° F. 50 grams, 5 sec. not more than 45.

BLOCK STONE PAVEMENT

(City of Rochester, N. Y., Specifications, 1911)

Paving blocks shall consist of the best quality of Medina sandstone free from quarry checks or cracks, and shall be quarried from fine-grain live rock, showing a straight and even fracture. The material shall be of uniform quality and texture, free from seams or lines of clay or other substances which, in the opinion of the City Engineer, will be injurious to its use as paving material.

Blocks shall measure not less than three (3) nor more than six (6) inches thick, and not less than six (6) nor more than six and one-half (6½) inches deep, and from seven (7) to twelve (12) inches in length. Stones to have parallel sides and ends, and right-angle joints. All roughness in joints of stone to be broken off, so that when set in place they shall have tight joints for a distance of at least two and one-half (2½) inches from the top down. The top to have a smooth even surface, with no projection or depression exceeding one-quarter (¼) inch.

When approved by the City Engineer, paving blocks of the following dimensions may be used.

Three to five inches in width; five inches in depth, with an allowable variation of one-quarter inch, more or less, in said depth, and seven to twelve inches in length.

Paving blocks as here referred to shall be understood to mean blocks of Medina sandstone, prepared in the usual manner for dressed block paving by nicking and breaking the stone from larger blocks, as is done at the quarries where such blocks are usually prepared, and not made by redressing or selecting from common stone paving material.

The stones will be carefully inspected after they are brought on the line of the work, and the blocks which, in quality and dimensions, do not conform strictly to these specifications, will be rejected and must be immediately removed from the line of the work. The contractor will be required to furnish such laborers as may be necessary to aid the inspector in the examination and the culling of the blocks.

The stones brought upon the ground having been carefully and thoroughly inspected, as provided for herein, and all rejected stones removed from the line of the work, the contractor will then be required to pile such stone as may have been approved, neatly, on the front of the sidewalk, and not within three (3) feet of any fire hydrant, and in such manner as will preserve sufficient passageway, on the line of the sidewalks, and also permit of free access from the roadway to each entrance on the line of the street.

SECOND QUALITY BLOCKS

(THE FOLLOWING NOT IN ANY SPECIFICATIONS)

Second quality block, known as pavers, are practically the same material as the first quality block, the only difference being a greater range of size and a less careful top and joint finish. They cost $0.50 per square yard less. These pavers can be furnished under a specification allowing the following range of size and joint width:

(CITY OF CLEVELAND SPECIFICATIONS)

"Common paving stones shall consist of the best quality of Medina sandstone, and shall be not less than three (3) nor more than five (5) inches thick, and not less than seven (7) nor more than eight (8) inches deep, and from eight (8) to thirteen (13) inches long. The stones to have parallel sides and ends, with right-angle joints, all roughness and points of stone to be broken off so that when set in place they shall have tight joints for a distance of at least three inches from the top; the area of the bottom of any stone to be not less than three-quarters (3/4) of the area of the top; the top of all stones to have a smooth even surface."

CAST-IRON PIPE

Cast-iron pipe shall be light weight and may be second quality, but it shall be free from all defects impairing its strength. The iron must be of good quality, uniform in thickness and of full strength, and the pipe shall be coated with coal pitch varnish mixed with linseed oil to form a firm tough coating. The joint shall be formed by calking into the hub a gasket of jute or oakum and then filling with mortar formed of equal parts of Portland Cement and clean sharp sand.

MESH REINFORCEMENT

Mesh reinforcement shall be placed where called for on the plans or ordered by the engineer. It shall be of medium steel.

If expanded metal is used it shall conform to the above requirements and the weight per square foot shall be as shown on the standard structure sheet, and any reinforcement shall be of a character that it will distribute the loads evenly.

DEFORMED BARS

Deformed bars shall be placed where called for on the plans or ordered by the engineer. They shall be of medium steel and shall have a deformed cross-section, that is, the various cross-sections must be of different shape or their centers must not lie in the same axis.

CAST IRON

Cast iron shall be of full standard pattern for shapes or forms used, according to drawings or detailed specifications. All cast iron shall be of good gray iron, free from blows, sand holes, or other defects, and shall have a tensile strength of not less than 17,000 pounds per square inch of section.

WROUGHT IRON

Wrought iron shall be tough, fibrous, and uniform in quality and shall be manufactured by approved methods. Steel scrap shall not be used in its manufacture. Finished material shall be clean, smooth, straight, true to shape, of workmanlike finish and free from defects.

Test pieces cut from finished material shall show an ultimate tensile strength of not less than 48,000 pounds per square inch, an elastic limit of not less than 25,000 pounds per square inch, and an elongation of not less than 20 % in 8 inches.

Wrought-iron test pieces cut from finished material when cold, or when heated to a bright, cherry-red, shall endure bending 180 degrees around a circle whose diameter is equal to twice the thickness of the test piece, without signs of cracking. Test pieces when nicked and broken shall show a fracture not less than 90 % fibrous, free from coarse, crystalline spots.

Wrought iron when welded shall not show signs of red shortness.

STEEL

1. Steel, except as otherwise provided by these specifications, shall be made by the acid or basic open-hearth process and shall be uniform in character; finished material shall be clean, smooth, straight, true to shape, of workmanlike finish, and free from defects.

2. Fractures must show a uniform fine grain of a blue, steel-gray color entirely free from a fiery luster or a blackish cast.

3. No work shall be put upon any steel at or near the blue temperature or between the temperature of boiling water and of the ignition of hardwood sawdust.

4. No sharp or unfilleted corners will be allowed in any piece of metal.

5. **Annealing.**—Crimped stiffeners and buckled plates need not be annealed. All other steel that has been bent cold or partially heated and all forgings must be wholly annealed; exception may be made in unimportant cases and then only upon written permission from the Commission.

6. Tests of steel that is to be annealed shall be made after annealing, or strips cut from such steel shall be annealed at the same time, before testing.

7. **Tests of Medium Steel.**—Test pieces cut from finished material shall show an ultimate strength of not less than sixty thousand (60,000) pounds per square inch and not more than sixty-eight thousand (68,000) pounds per square inch, an elastic limit of not less than thirty-five thousand (35,000) pounds per square inch, an elongation of not less than twenty-two (22) per cent. in eight (8) inches, and a reduction of area at the fracture of not less than forty (40) per cent.

8. Medium steel shall not contain more than five one-hundredths (5–100) of 1 % of sulphur.

9. Acid steel shall not contain more than eight one-hundredths (8–100) of 1 %, and basic steel shall not contain more than four one-hundredths (4–100) of 1 % of phosphorus.

10. Medium steel shall endure bending cold or after quenching from a red heat in water at 80°F., 180° around a circle whose diameter is equal to the thickness of the test piece, without signs of cracking.

11. **Tests for Soft Steel.**—Test pieces cut from finished material shall show an ultimate strength of not less than fifty thousand (50,000) pounds per square inch and not more than fifty-eight thousand (58,000) pounds per square inch, an elastic limit of not less than thirty thousand (30,000) pounds per square inch, an elongation of not less than 28 % in eight inches, and a reduction in area at the fracture of not less than fifty (50) per cent.

12. Soft steel shall not contain more than four one-hundredths (4–100) of 1 % of sulphur.

13. Acid steel shall not contain more than six one-hundredths (6–100) of 1 %, and basic steel shall not contain more than four one-hundredths (4–100) of 1 % of phosphorus.

14. Soft steel shall endure bending flat upon itself without signs of cracking, when cold, or after quenching, from a red heat, in water at eighty (0) degrees F.

VITRIFIED PIPE

Vitrified pipe shall be double strength salt-glazed vitrified stoneware sewer pipe of the first quality (for dimensions and weights see page 560). The item will include the furnishing delivering, handling, laying, and cementing of joints; also the operations of excavating the trench, bracing, sheeting, or otherwise supporting the sides, grading and preparing the bottom, backfilling and compacting to the original surface, and the removal of all surplus material.

PIPE CULVERTS (U. S. FOREST ROAD SPECIFICATIONS)

Pipe culverts shall be constructed wherever indicated on the plans or directed by the engineer. Typical plans for the guidance of the contractor will be furnished for each particular kind of pipe culvert required. The

ends of all pipe culverts shall be protected by concrete or masonry end walls unless otherwise ordered by the engineer.

Concrete Pipe.—Concrete pipe must be dense, smooth and free from any imperfection that would impair the strength. The concrete shall be mixed in the proportion of one (1) part Portland cement, two (2) parts sand, and one and one-half (1½) parts clean pea gravel (all of which shall pass a screen having three-fourths (¾) inch circular openings and be retained on a screen having one-quarter (¼) inch circular openings. It shall be thoroughly mixed with water and tamped into properly shaped forms. All materials shall conform to the requirements for *Concrete* and *Reinforcement* herein specified.

The thickness of pipe shall not be less than that shown in the following table of dimensions:

Inside Diameter	Thickness
12 inches	2 inches
18 "	2½ "
24 "	3 "
30 "	3½ "
36 "	4 "
42 "	4½ "
48 "	5 "

All pipe shall be reinforced with triangular mesh or other type of reinforcement approved by the engineer, and shall conform to the following table of sizes and weights:

Diameter of Pipe	Triangular Reinforcement—four-inch mesh
12 inches	Minimum weight, 0.20 lb. per sq. ft.
18 "	" " 0.30 " " " "
24 "	" " 0.35 " " " "
30 "	" " 0.40 " " " "
36 "	" " 0.50 " " " "
42 "	" " 0.60 " " " "
48 "	" " 0.60 " " " "

Joints of the reinforced concrete pipe shall be of the lock type, bell and spigot or other approved type, with positive connection between sections of pipe.

Cast-iron Pipe.—Cast-iron pipe shall be made with bell and spigot joints, and shall conform to the following table of minimum weights and thickness:

Inside Diameter Inches	Thickness Inches	Weight per Foot Pounds
12	0.54	72.5
14	0.57	89.6
16	0.60	108.3
18	0.64	129.2
20	0.67	150.0
24	0.76	204.2
30	0.88	291.7
36	0.99	391.7

The weight shall not be less than the standard weight by more than five (5) per cent. The pipe shall be straight and the inner and outer surfaces shall be true concentric cylinders. All pipe shall be made of cast iron of good quality and of such character that the metal of the pipe will be strong, tough and of fine grain, and soft enough satisfactorily to admit of drilling and cutting. The metal shall be made without any mixture of cinder-iron or other inferior metal. The surfaces of the pipe shall be smooth, free from scales, lumps, blisters, and holes, and defects of every nature which unfit the pipe for the use for which it is intended.

The pipe shall be coated inside and out with coal-tar pitch varnish. The varnish shall be made of coal tar to which sufficient oil has been added to make a smooth coating, tough and tenacious when cold, but with no tendency to crack or scale.

(5) All bituminous material T. will be sampled by an Engineer of the Department of Highways, and samples sent to the Bureau of Tests, Albany, N. Y.

Item 72—Specification for Bituminous Material T (Bituminous Macadam)

LOW CARBON—BINDER

This bituminous material shall have the following characteristics:

(1) It shall be free from water.

(2) It shall be uniform in character, appearance and viscosity.

(3) It shall have a specific gravity not less than 1.16 at 25 degrees Centigrade.

(4) It shall contain not more than 5 per centum free carbon.

(5) When distilled by the method of the American Society for Testing Materials, it shall contain no body that distils at a lower temperature than 170 degrees Centigrade; not over 5 per centum shall distil below 235 degrees Centigrade; not over 15 per centum shall distil below 270 degrees Centigrade; not over 20 per centum shall distil below 300 degrees Centigrade. The residue from the foregoing distillation shall have a melting point not greater than 75 degrees Centigrade ball and ring method.

(6) It shall have a melting point of not less than 27 degrees C., and not more than 34 degrees C., by ball and ring method.

(7) All bituminous material T. will be sampled by an Engineer of the Department of Highways, and samples sent to the Bureau of Tests, Albany, N. Y.

Item 73—Specification for Bituminous Material T (Surface Treatment)

LOW CARBON—HOT APPLICATION

This bituminous material shall have the following characteristics:

(1) It shall be free from water.

(2) It shall be uniform in character, appearance and viscosity.

(3) It shall have a specific gravity of not less than 1.14 at 25 degrees Centigrade.

(4) It shall contain not more than 4 per centum of free carbon.

(5) When distilled by the method of the American Society for Testing Materials, not over 1 per centum shall distil below 170 degrees Centigrade; not over 12 per centum shall distil below 235 degrees Centigrade; not over 20 per centum shall distil below 270 degrees Centigrade, and not over 25 per centum shall distil below 300 degrees Centigrade. The residue from the foregoing distillation shall have a melting point not greater than 75 degrees Centigrade ball and ring method.

(6) It shall have a float test (New York Testing Laboratory method) at 100 degrees Centigrade between fifteen and twenty-five seconds.

(7) All bituminous material T. will be sampled by an Engineer of the Department of Highways, and samples sent to the Bureau of Tests, Albany, N. Y.

Item 74—Specification for Bituminous Material T (Surface Treatment)

LOW CARBON—COLD APPLICATION

This bituminous material shall have the following characteristics:

(1) It shall have a specific gravity of 1.10 to 1.13 at 25 degrees Centigrade.

(2) It shall contain not more than 2 per centum of free carbon.

(3) When distilled by the method of the American Society for Testing Materials, not over 5 per centum shall distil below 170 degrees Centigrade; not over 20 per centum shall distil below 235 degrees Centigrade; not over 28 per centum shall distil below 270 degrees Centigrade, and not over 35 per centum shall distil below 300 degrees Centigrade. The residue from the foregoing distillation shall have a melting point not greater than 70 degrees Centigrade ball and ring method.

(4) The viscosity when tested by the standard Engler viscosimeter shall not be more than 125 seconds at 60 degrees Centigrade for the first 100 cubic centimeters.

(5) All bituminous material T. will be sampled by an Engineer of the

quirements of cement for "*Concrete*," and two parts of approved, clean sand mixed with sufficient water to form a plastic mortar.

When corrugated metal pipe sections are to be joined on the work the ends shall be butted together and the sections joined with the band coupler securely bolted in place.

The filling around the pipe shall be made in layers with approved material free from rock and each layer shall be tamped thoroughly around and over the pipe to the elevation of the original ground surface. The material supporting the lower half circumference of the pipe shall be uniformly and securely tamped to give proper support without displacing the pipe.

Payment.—All pipe culverts will be paid for by the linear foot in place at the respective prices bid for the different kinds of pipe. These prices shall be payment in full for all pipe, joint material, etc., and for all labor employed in excavation, backfilling, laying the pipe and filling the joints, but will not include payment for masonry or concrete end walls.

POROUS TILE (NEW YORK STATE SPECIFICATIONS)

Where called for on the plans, or ordered by the engineer, porous tile shall be laid true to line and grade, and firmly bedded in clean cinders, gravel, or crushed stone. The tile must be whole and free from cracks and other defects, and must be satisfactory to the engineer.

TIMBER

(Washington State Specifications)

Quality of Timber and Plank.—All timber and plank in culverts, trestlework, bridge abutments, and pile bridges shall be of good quality, of such kinds as the highway commissioner may direct, free from shakes, wanes, black and unsound knots, and all descriptions of decay, and shall be measured by the thousand feet, board measure; the price shall be understood to cover the expense of all labor (including all necessary digging and filling at the ends of bridges where grading is done before bridges are put in) and materials, pins, or treenails required in the performance of the work.

All timber structures shall be built in conformity with plans to be furnished by the engineer.

Piles and Pile-driving.—Piles, whether used in foundations, trestlework, or pile bridges, shall be of good, sound quality of such timber as the Highway Commissioner may accept, not less than ten inches in diameter at the smaller end and of such lengths as the engineer may require. They shall be measured by the lineal foot after they are driven and cut off to receive the superstructure, and the price per lineal foot shall be understood to cover the expense of driving, cutting off, removing the bark from the part above the ground, and all other labor and material required in the performance of the work; but that portion of each pile cut off shall be estimated and paid for by the lineal foot as "piling cut off." Piles shall be driven of such lengths and to such depths as the engineer may require. All piles shall be capped during the driving to prevent brooming.

LOG CULVERTS (U. S. FOREST ROAD SPECIFICATIONS)

Log culverts shall be constructed in conformity with the plans, or where directed by the engineer.

Materials.—In the construction of log culverts the timber shall be of the species called for on the plans. All knots and projections shall be trimmed down even with the surface of the log, and all bark shall be peeled off before the logs are used.

If Government owned stumpage is available the logs may be cut either from the right-of-way or adjacent Government land, as the engineer may direct, and the engineer will in all such cases indicate the trees to be used, which shall first have been designated by a forest official. The tops and branches of trees shall be disposed of as provided in the specifications for "Clearing and Grubbing," hereinbefore given. The stringer logs shall be straight.

When suitable Government owned stumpage is not available the timber shall be furnished by the contractor at his own expense.

Construction.—The stakes set by the engineer shall control the line and elevation for each structure. If practicable the backfill within and behind the abutments shall be made of stone. Where no stone is available, the logs of the abutment shall be more carefully hewn so as to form close joints that will hold a backfilling of earth. In all cases the logs of the abutments shall be fastened together with five-eighths inch drift bolts.

The stringer logs shall be laid close enough together to hold the fill without leakage and an occasional stringer shall be spiked to the abutment in order to hold the roof of the culvert in place.

The crib wings shall be constructed in the same manner as the abutments.

Where a floor is called for, it shall be constructed of stringer logs and in the manner shown on the plans.

Payment.—Payment for log culverts shall be at the unit bid price per linear foot of culvert measured along the center line of culvert. The bid price for each size of culvert shall be payment in full for all labor and materials entering into any culvert of that size and the necessary excavation and backfilling therefor.

LOG BRIDGES (U. S. FOREST ROAD SPECIFICATIONS)

Log bridges shall be constructed in conformity with the plans or where directed by the engineer.

Materials.—The logs used in constructing log bridges shall be of the species called for on the plans. If Government owned stumpage is available, the logs may be cut either from the right-of-way or adjacent Government land, as the engineer may direct, and the engineer will in all such cases indicate the trees to be used, which shall first have been designated by a forest official. The tops and branches of trees shall be disposed of as provided in the specifications for "Clearing and Grubbing," as hereinbefore given.

When suitable Government owned stumpage is not available the timber shall be furnished by the contractor at his own expense.

The logs shall be straight, sound and free from defects of all kinds and shall be cut from live trees as far in advance of use as possible, but not exceeding one year, and be allowed to season with the bark on. Immediately before use in the work all bark shall be peeled and the logs trimmed smooth of all knots and projections.

All lumber for flooring, railings, etc., shall be of the kind and dimensions indicated on the plans and shall be free from shakes, wanes, black and unsound knots, and from all other defects which would impair its strength in any way.

The contractor shall furnish at his own expense all necessary bolts, drift bolts, spikes, nails and other material or hardware called for on the plans or in the specifications.

Construction.—The contractor shall provide experienced workmen and ample and suitable equipment and tools for performing the work, and shall follow only well recognized methods in preparing the timber and framing and erecting the structure.

Where concrete or masonry piers or abutments are called for on the plans, they shall be constructed in accordance with the requirements of the plans, and of the specifications hereinbefore given for the particular kind of concrete or masonry called for.

Payment.—Each log bridge superstructure complete will be paid for at the price bid per linear foot of bridge, as shown on the plans, which shall include all parts of the bridge except abutments and piers. This amount shall be payment in full for all materials, labor and incidentals, required to construct the bridges in accordance with the plans and specifications.

LOG ABUTMENTS FOR BRIDGES

Log abutments for bridges will be built according to the specifications for "Log Cribbing," and as shown on the plans, and will be paid for as "Log Cribbing."

LOG CRIBBING (U. S. FOREST ROAD SPECIFICATIONS)

Log cribbing shall be built to the lines and grades given by the engineer and constructed in conformity with the plans or as directed by the engineer.

Materials.—The contractor shall secure and prepare or shall furnish at his own expense all necessary logs, timber, hardware, etc., under the conditions and as called for under the heading "Material" for "Log Bridges."

Construction.—The cribbing shall be supported on mudsills with flattened lower surfaces placed as shown on the plans.

All logs, including face logs, tie logs, mudsills and anchor logs, shall be properly notched together and drift bolted as shown on the plans.

The minimum lengths and sizes of logs shall be as shown on the plans. Each course of logs shall break joint with the adjacent courses. The lengths of tie logs required for the proper support and anchorage of the cribbing shall be as determined by the engineer.

The face and tie logs are to be so notched together, and hewn if necessary that the face logs will be in contact with each other throughout their entire length, except that in case a satisfactory rock backfill is placed against the face logs the engineer may permit open spaces not exceeding 4 inches in width between the face logs. When permission to use such spaces is given, the rock backfill shall be carefully placed, using the larger rocks adjacent to the logs and backing up with the smaller rocks in such manner that earth and finer material will not escape or be washed out.

Payment.—Payment will be made by the linear foot of face logs in place complete at the unit bid price, which price shall include the furnishing and placing of transverse mudsills, tie logs, anchor logs and drift bolts. Such unit bid price shall be payment in full for all materials, labor, excavation, backfilling and incidental work required for the construction of the cribbing complete. The measurement of log cribbing shall include only the linear feet of face logs, or longitudinal mudsills when such are used, and will not include transverse mudsills, tie logs or anchor logs.

CLEARING AND GRUBBING (WASHINGTON STATE SPECIFICATIONS)

Clearing.—The right-of-way must be cleared to the width of —— feet on each side of the center line, or as shall be designated by the engineer; all trees, brush, and other vegetable matter within the space designated to be cut down, and the same, together with all other logs, brushwood, and fences already down, shall be burned or removed from the grounds, as the engineer may direct, so as not to injure the adjoining lands or to obstruct the line of the fences along the boundaries of the said right-of-way. When the embankments exceed two feet in height it will be required to cut the trees, brush, and stumps close to the ground.

Light clearing shall include the removal of all standing trees of a size up to one foot in diameter, together with all other logs, brush, and other vegetable matter already down or lying loose on the ground.

Heavy clearing shall include the removal of all standing trees over one foot in diameter, together with all other logs, brush, and other vegetable matter already down or lying loose on the ground.

Grubbing.—From the space required for the roadbed and necessary slopes and side drains, and whatever additional space may be required by the engineer, except where the excavations are three feet or more in depth, or embankments two feet or more in height, all stumps and other wood or vegetable matter embedded in the ground shall be grubbed up, and removed or disposed of as the engineer may direct, and only the area so grubbed shall be estimated.

Clearing and Grubbing (U. S. Forest Road Specifications).—This item shall include all clearing, grubbing and disposal of timber.

The right-of-way must be cleared on each side of the center line of the road to the full width indicated by the plans, or as the engineer may require. All trees, brush and other vegetable matter within the space designated shall be cut down and all tree branches extending into the right-of-way which hang within 20 feet of the ground shall be cut off. The edge of the clearing shall present a fairly regular and uniform alignment, except that fine specimens of trees shall be left standing when in the judgment of the engineer they will not be injurious to the road. All stumps and all trees, the stumps of which are not to be grubbed, shall be cut not more than 2 feet above the ground.

From the space required for the roadbed and necessary slopes and side drains except where the embankments at the point in question are three feet

onstruction.—The stakes set by the engineer shall control the line and ation for each structure. If practicable the backfill within and behind abutments shall be made of stone. Where no stone is available, the of the abutment shall be more carefully hewn so as to form close joints t will hold a backfilling of earth. In all cases the logs of the abutments ll be fastened together with five-eighths inch drift bolts.

The stringer logs shall be laid close enough together to hold the fill without kage and an occasional stringer shall be spiked to the abutment in order hold the roof of the culvert in place.

The crib wings shall be constructed in the same manner as the abutments. Where a floor is called for, it shall be constructed of stringer logs and in manner shown on the plans.

Payment.—Payment for log culverts shall be at the unit bid price per ear foot of culvert measured along the center line of culvert. The bid ce for each size of culvert shall be payment in full for all labor and materials entering into any culvert of that size and the necessary excavation and ckfilling therefor.

LOG BRIDGES (U. S. FOREST ROAD SPECIFICATIONS)

Log bridges shall be constructed in conformity with the plans or where rected by the engineer.

Materials.—The logs used in constructing log bridges shall be of the species lled for on the plans. If Government owned stumpage is available, the gs may be cut either from the right-of-way or adjacent Government land, the engineer may direct, and the engineer will in all such cases indicate e trees to be used, which shall first have been designated by a forest official. he tops and branches of trees shall be disposed of as provided in the specications for "Clearing and Grubbing," as hereinbefore given.

When suitable Government owned stumpage is not available the timber iall be furnished by the contractor at his own expense.

The logs shall be straight, sound and free from defects of all kinds and iall be cut from live trees as far in advance of use as possible, but not exeeding one year, and be allowed to season with the bark on. Immediately efore use in the work all bark shall be peeled and the logs trimmed smooth f all knots and projections.

All lumber for flooring, railings, etc., shall be of the kind and dimensions idicated on the plans and shall be free from shakes, wanes, black and unound knots, and from all other defects which would impair its strength in ny way.

The contractor shall furnish at his own expense all necessary bolts, drift olts, spikes, nails and other material or hardware called for on the plans r in the specifications.

Construction.—The contractor shall provide experienced workmen and mple and suitable equipment and tools for performing the work, and shall ollow only well recognized methods in preparing the timber and framing nd erecting the structure.

Where concrete or masonry piers or abutments are called for on the plans, hey shall be constructed in accordance with the requirements of the plans, nd of the specifications hereinbefore given for the particular kind of conrete or masonry called for.

Payment.—Each log bridge superstructure complete will be paid for at he price bid per linear foot of bridge, as shown on the plans, which shall nclude all parts of the bridge except abutments and piers. This amount hall be payment in full for all materials, labor and incidentals, required to onstruct the bridges in accordance with the plans and specifications.

LOG ABUTMENTS FOR BRIDGES

Log abutments for bridges will be built according to the specifications for 'Log Cribbing," and as shown on the plans, and will be paid for as "Log Cribbing."

LOG CRIBBING (U. S. FOREST ROAD SPECIFICATIONS)

Log cribbing shall be built to the lines and grades given by the engineer ınd constructed in conformity with the plans or as directed by the engineer.

Solid Rock.—Solid rock will include all rock in place, and boulders measuring one-half cubic yard and upwards, in removing which it is necessary to resort to drilling and blasting.

Shell-rock Excavation.—Shell-rock excavation will include all deposits composed entirely of rock in masses of less than one cubic foot which have broken off from the cliffs above the roadbed, but will only be estimated when in large deposits.

Solid Rock Borrow.—Solid rock borrow shall consist of solid rock, according to above classification, excavated outside of the regular cross-sections of the cuts for the roadbed, and placed and measured in embankment.

EXCAVATION (NEW YORK STATE SPECIFICATIONS, ITEMS NO. 1 TO 46)

Item 2—Earth Excavation

Item 3—Rock Excavation

2.1. Under these items the Contractor shall grade the entire length of roadway, ditches and side slopes to the required lines and grades; shall make all excavations for culverts, under-drains, catch basins, leaching basins, and other structures except posts; shall grade connecting public highways as directed and remove spongy material from the sub-grade to the depths required—all as shown on the plans or as directed by the Engineer.

This item includes the excavation, filling and rolling necessary to complete the road and all structures connected therewith except as noted above, and includes the removal of all objectionable material for the full width of the improvement except as noted under section 1.1, and the filling to the required grade with acceptable material of all areas originally below the required grade, or excavated below grade under orders of the Engineer.

Backfill for structures, old macadam excavated, and sod ordered removed from the site of a new embankment, shall be paid for as EARTH EXCAVATION.

2.2. All suitable materials from the excavation shall be used so far as practicable in making embankments, building up low places on the subgrade or shoulders, and such other places as directed.

2.3. Surplus material shall be placed in embankments, shall be used for extending the shoulders or shall be deposited in spoil banks, as directed by the engineer. All surplus materials shall be removed and disposed of as directed by the engineer before the sub-grade or shoulder rolling is completed and before any stone is placed on the roadway.

2.4. If there is not sufficient suitable material to complete the grading and to bring the sub-grade to the required height, the contractor shall borrow additional material from the sides of the roadway or from other borrow pits as directed by the engineer so that the established grade for the road, embankments, etc., will be secured. All borrow pits outside the highway shall be acquired by the Contractor at his own expense, and any borrow pits in or adjacent to the highway shall be left in a neat and satisfactory condition and shall be thoroughly drained.

2.5. The contractor shall remove boulders and all muck, quicksand, soft clay and spongy material which will not consolidate under the roller, from the sub-grade to a depth to be determined by the engineer, and refill the space with acceptable materials from the excavations, or with stone or gravel, as directed. If stone or gravel is used, the same will be paid for at the contract price bid for item "FOUNDATION COURSE." After all drains have been laid and the surface of the sub-grade has been properly shaped, it shall be thoroughly rolled and compacted with an approved self-propelled roller weighing not less than 10 tons. Water puddling shall be resorted to in case the soil requires it. Care shall be taken not to roll clay foundations too much, thus developing a plastic condition. All hollows and depressions which develop shall be filled with acceptable material, and the sub-grade shall again be rolled. This process of filling and rolling shall be repeated until no depressions develop. In places where the character of the material makes the use of such a roller impracticable, a lighter one may be permitted. The sub-grade shall not be muddy, or otherwise unsatisfactory when the foundation course is placed upon it. All culverts, ditches, and drains shall be satisfactorily completed to effectively drain the highway before the placing of any pavement will be permitted. The shoulders shall be rolled and left in a compact and satisfactory condition at the completion of the pavement.

2.6. Embankment shall be formed of suitable materials. If formed of stone, all reasonable precautions must be taken to insure a solid embankment. The upper surface of the embankment shall be rolled and left in a satisfactory condition and approximately true to line and grades. Large stone shall not project within 6 inches of the finished sub-grade, and all hollows, and depressions shall be filled with the smaller stone from the excavation, with gravel or with other acceptable material. Stone in embankments shall not be used nearer than 6 inches to the surface of shoulder.

Where the filling is less than 2 feet in depth all vegetable matter shall be removed from the original surface. Where necessitated by the existing slope, the original surface shall be trenched or otherwise broken up before placing new embankment thereon.

Embankment shall be constructed in successive horizontal layers not exceeding 12 inches in thickness; when concrete is to be placed thereon, these layers shall not exceed 6 inches in thickness. Each layer shall extend across the entire fill and shall be thoroughly rolled and compacted by approved methods. If impracticable to use a heavy roller for this work a grooved roller shall be used.

2.7. At all intersecting public highways the contractor shall grade back to a sufficient distance with acceptable materials, as directed by the engineer so that a smooth riding and satisfactory junction will be produced.

2.8. The quantity of excavation to be paid for under Items 2 and 3 shall be the number of cubic yards of material, measured in its original position, excavated and disposed of as directed by the Engineer, and the limits shall not exceed those shown upon the plans or fixed by the Engineer.

The price bid for EARTH EXCAVATION shall include the removal of all materials, as specified under section 2.1—except as provided below for "ROCK EXCAVATION,"—the placing of same in embankment or spoil, the rolling, compacting, grading and all other work incidental thereto.

No direct payment shall be made under Items 2 or 3 for work in connection with contractor's plant, nor for his other requirements in carrying out the provisions of this contract, but compensation therefor shall be considered as having been included in the prices stipulated for the various items of the contract.

The price bid for Item 3 shall include the removal of all boulders of more than 13 cubic feet and all hard ledge rock and the placing of same in embankment or spoil if not used under other items of the contract, and rolling, compacting, grading and all other work incidental thereto. Boulders of less than 13 cubic feet, and all soft or disintegrated rock which can be removed with pick and shovel, shall not be paid for under ROCK EXCAVATION, but under "EARTH EXCAVATION." The price bid for the items shall include all labor, materials, supplies, and plant and incidentals necessary to complete the work.

Item 4—Overhaul

4.1. If the haul on any material either from cuts or borrow pits made in accordance with directions from the Engineer exceeds 2000 feet it shall be classified as overhaul.

For each 100 feet of haul greater than 2000 feet the Contractor shall receive the price bid for Overhaul per cubic yard of all material so moved, measured in its original position.

The price bid shall include all labor, appliances, and incidentals necessary to complete the work.

Item 5—Vitrified Clay Pipe

5.1. Under this item the Contractor shall furnish and place vitrified pipe where directed by the Engineer.

5.2. Pipe shall be first quality, double strength, salt glazed, sound, vitrified, stoneware sewer pipe with bell joints. (For dimensions and weight of vitrified pipe see page 560.)

5.3. All pipe shall be laid true to line and grade with bells upstream, and shall have a full, firm and even bearing. The joints shall be filled with jute and mortar consisting of one part Portland cement and two parts sand.

5.4. The quantity to be paid for under this item shall be the number of linear feet of pipe incorporated in the work under the directions and to the satisfaction of the Engineer.

The price bid shall include the furnishing and laying and all materials

and incidentals necessary thereto, except that all excavation in connection therewith will be paid for under item "EXCAVATION."

Item 6—Vitrified Clay Underdrains

6.1. Under this item the Contractor shall furnish and lay 6-inch salt glazed vitrified pipe wherever required for drainage.

6.2. The pipe shall be laid true to line and grade with the bells up grade. A strap of burlap at least 6 inches wide and long enough to reach around the pipe and lap at least 1 foot shall be wrapped around each joint of pipe to give double thickness on the top and to act as a strainer. The pipe shall be covered as laid with clean gravel or broken stone of No. 2 or No. 3 size placed around and above it to the surface of the sub-grade.

6.3. The amount to be paid for under this item shall be the number of linear feet of pipe furnished and incorporated in the work.

The price bid shall include all labor, materials, and incidentals necessary to complete the work, except that the necessary excavation will be paid for under item "EXCAVATION," and the necessary broken stone will be paid for under item "BROKEN STONE, LOOSE MEASUREMENT."

Item 7—Porous Tile Underdrain

7.1. Under this item the Contractor shall furnish and lay 6-inch porous tile wherever required for drainage.

7.2. The tile must be whole and free from cracks and other defects, and must be satisfactory to the Engineer.

7.3. The tile shall be laid true to line and grade and shall be covered as laid with clean gravel or broken stone placed around and above it to the surface of the sub-grade.

7.4. The amount to be paid for under this item shall be the number of linear feet of pipe furnished and incorporated in the work.

The price bid shall include all labor, materials, and incidentals necessary to complete the work, except that the necessary excavation will be paid for under item "EXCAVATION," and the necessary broken stone will be paid for under item "BROKEN STONE, LOOSE MEASUREMENT."

Item 8—Concrete Leaching Basins

8.1. Under this item the Contractor shall build at places indicated on the plan or ordered by the Engineer, concrete leaching basins of a type shown on the detail plans.

8.2. The concrete used in these basins shall be second-class concrete.

8.3. The grating shall be of cast iron of the quality specified in item "MISCELLANEOUS IRON AND STEEL."

8.4. For each basin completed, the Contractor shall receive the price bid.

The price bid shall include all concrete, stone, grating, and all material labor and incidentals necessary to complete the work, except that the excavation will be paid for under item "EXCAVATION."

Item 9—Vitrified Leaching Basins

9.1. Under this item the Contractor shall build at places indicated on the plans or ordered by the Engineer, leaching basins of a type shown on the detail plans.

9.2. Vitrified pipe shall be of double thickness, sound, and thoroughly tamped in place.

9.3. The broken stone used for filling shall be No. 4 broken stone or gravel.

9.4. The grating shall be of cast iron of the quality specified in item "MISCELLANEOUS IRON AND STEEL."

9.5. For each basin completed in accordance with plans and under orders of the Engineer, the Contractor shall receive the price bid.

The price bid shall include all materials, labor and appliances, and all expenses incidental to completing the work, except the excavation—which last will be paid for under item "EXCAVATION."

Item 10—Catch Basins

10.1. Under this item the Contractor shall build catch basins as shown on the plans, as directed by the Engineer.

10.2. The catch basins may be built of second-class concrete or of acceptable brick at the option of the Contractor. If bricks are used they shall be sound, hard burned brick of acceptable quality, and shall be laid by a competent mason and in a workmanlike manner. Mortar of one part Portland cement and two parts sand shall be used.

10.3. For each catch basin complete with cast iron top, as shown on plans and ordered by the Engineer, the Contractor shall receive the price bid.

The price bid shall include all labor, materials and incidentals required to complete each basin, except that the excavation will be paid for under item "EXCAVATION."

DROP INLETS

Drop inlets shall be constructed where shown upon the plans, or directed by the Engineer. The details of construction shall be such as he may direct.

Payment for drop inlets will be made under appropriate items at the contract price for the materials entering into their construction; that is, payment will be made for the various amounts of excavation, concrete, cast iron, cast-iron pipe, etc. Payment under these items shall include all labor and materials necessary to complete the work.

Item 11—Changing Elevation of Manholes and Catch Basins

11.1. Under this item the Contractor shall raise or lower to the grade given all existing covers of catch basins or manholes.

11.2. All changes shall be made with acceptable brick laid in Portland cement mortar of one part cement and two parts sand.

All work shall be done in a workmanlike manner by competent masons.

11.3. For each manhole or catch basin raised or lowered as directed by the Engineer, the Contractor shall receive the unit price bid.

The price bid shall include all labor, materials and incidentals necessary to complete the work. If any manhole or catch basin heads or covers are broken through carelessness on the part of the Contractor, they shall be replaced at his expense.

Item 12—Cast-iron Pipe

12.1. Under this item the Contractor shall furnish and place cast-iron pipe as directed for culverts, drains and other necessary uses, and of the sizes and weights ordered.

12.2. Pipe shall be of class A unless otherwise called for by the plans or ordered in writing by the Division Engineer, and may be second quality; but it shall be free from all defects impairing its strength or utility. The iron must be of good quality, uniform in thickness and of full strength. The pipe shall be coated with coal-pitch varnish mixed with linseed oil to form a firm, tough coating. Joints shall be formed by caulking into the hubs a gasket of jute or oakum and then filling with mortar composed of equal parts of Portland cement and clean, sharp sand. It shall be laid true to line and grade and shall have a full, firm, even bearing.

12.3. The number of tons of cast-iron pipe to be paid for under this item shall be the actual weight in place in the work as directed by the Engineer when of class A, or an equal weight when of heavier class; except that when a heavier weight is used under written order of the Division Engineer, such weight shall be paid for.

The price bid shall include the furnishing, delivering, handling, laying, cutting and all work and materials necessary to complete the work.

Item 13—Relaying Old Pipe

13.1. Under this item the Contractor shall as directed carefully remove, preserve and relay old pipe found in existing culverts.

13.2. The old pipe when relaid shall be true to line and grade and have a full, firm, even bearing, and the work shall be in every way the same as if new pipe were being laid.

13.3. Any old pipe in good condition which is damaged in removing, due to the carelessness of the Contractor, shall be replaced with new pipe at the Contractor's expense.

Any old pipe which is, in the Engineer's judgment, unfit for relaying may be destroyed before removing.

13.4. The amount to be paid for under this item shall be the number of linear feet incorporated in the work. New pipe furnished to replace old pipe which is destroyed through the carelessness of the Contractor shall be paid for as if the old pipe had been preserved and relaid.

The price bid shall include all labor, materials and incidentals necessary to complete the work, except that the excavation necessary will be paid for under the item "EXCAVATION."

Item 14—Stone Filling

14.1. Under this item the Contractor shall furnish and place acceptable stone of either quarry, field or cobble stone for filling crib work, and similar work as required.

14.2. Stone filling shall be of acceptable quarry, field or cobble stone. The larger stones shall be properly embedded at the bottom of the fill; all stones shall be so placed as to make a fill of maximum stability.

14.3. The quantity to be paid for under this item shall be the number of cubic yards measured in its final position and incorporated in the work as directed by the Engineer. The price stipulated shall include the cost of obtaining the stone, placing, and all materials and expenses incidental thereto.

Item 15—Piles

15.1. Under this item the Contractor shall furnish and drive piles of acceptable material and lengths for foundations, revetment and elsewhere as required.

15.2. Piles shall be furnished to fit the localities. The Contractor shall, when required, drive preliminary test piles, each of which will be paid for at the contract price therefor. After the test piles are driven a statement will be furnished the Contractor by the Engineer, showing for the information of the Contractor the probable number of piles of the different kinds required, grouped between certain lengths in feet.

15.3. Piles shall be driven by hammer or combination of hammer and water jet methods, and the driving shall be satisfactory to the Engineer in every case. In driving piles the heads shall be protected from injury by a cap or shall be banded if required. The fall of the hammer shall not exceed 20 feet, and shall be regulated so as not to injure or shatter the pile. Driving shall continue until the penetration and bearing values are satisfactory to the Engineer.

15.4. The tops of all piles shall be sawed level and true to the elevation fixed by the Engineer.

15.5. Broken, split or misplaced piles shall be drawn and properly replaced. Piles driven below the grade fixed by the Engineer shall be drawn and replaced by new, and if necessary, longer, piles. No payment will be made for driving or withdrawing piles so injured or misplaced.

15.6. The number of linear feet paid for under this item shall be the total length of piles driven in accordance with plans or orders of the Engineer.

The price bid shall include the furnishing and delivering upon the work the peeling, banding, tenoning, framing, driving, painting and all other labor and incidentals necessary to complete the work.

Item 16—Timber and Lumber

16.1. Under this item the Contractor shall furnish timber and lumber of various sizes as may be ordered for sills or platforms beneath the road for culverts, bridges, reinforcing existing structures and for other similar purposes as ordered by the Engineer.

16.2. Timber and lumber shall be of short leaf yellow pine or spruce

or other acceptable kind, sound, square-edged, free from shakes, loose knots or decay, and shall be planed, and tongued-and-grooved if required.

16.3. No payments will be made under this item for timber or lumber for forms, moulds, or centers, for sheeting or bracing, scaffolds, fences, guard rails or any part of the contractor's temporary bridges, roads, or plant; but payment for timber and lumber used in the above cases shall be included under the appropriate items covering the same.

16.4. The quantity of timber and lumber to be paid for shall be the number of thousand feet, board measure, actually placed in accordance with orders of the Engineer. If any round timber is used it shall be estimated as square timber of the largest size, omitting fractions of an inch, which can be inscribed in the small end of the log.

No second hand timber shall be used except with the approval of the Engineer. The price bid shall include all bolts, spikes and other fastenings and all other material expenses incidental to furnishing, framing and placing the timber and lumber satisfactorily.

Item 17—Rip-rap

17.1. Under this item the Contractor shall furnish and place rip-rap for slope protection where shown upon the plans or ordered by the Engineer.

17.2. Rip-rap shall consist of field stone or rough, unhewn quarry stones as nearly cubical in form as is practicable, placed upon a slope not steeper than the angle of repose, and so laid that the weight of the large stones is carried by the soil and not by the stones adjacent. Fifty per centum of the mass shall be large stones of two cubic feet or more. The largest stones shall be placed first, roughly arranged and in close contact; the stones shall rest upon a 6-inch bed of stone chips or gravel or other acceptable porous material, where ordered by the Engineer. The spaces between the larger stones shall be filled with spalls of suitable size.

17.3. The quantity of rip-rap to be paid for under this item shall be the number of cubic yards placed in accordance with the plans or as directed by the Engineer. When a porous bed is placed in accordance with the directions of the Engineer, the quantity of the same shall be included in the quantity of rip-rap and paid for as such.

The price bid shall include all labor, materials and incidental expenses necessary to satisfactorily complete the work.

CONCRETE MASONRY

Item 18—First-Class Concrete

Item 19—Second-Class Concrete

Item 20—Third-Class Concrete

18.1. Under Items 18, 19 and 20 the Contractor shall place concrete of the class indicated on the plans or ordered by the Engineer, for culverts, abutments, wing walls and in other structures as directed by the Engineer.

This item shall not include concrete used in curbs, catch-basins, edging, sign posts, guard railing, resetting old curb, concrete pavement foundations or "Concrete Pavements" or in other structures for which there is a contract item, unless it is specifically stated under that item that such shall be the case. All concrete placed in the work, whether included under Items 18, 19, or 20 or under other items, shall conform to the requirements for concrete of the class specified.

18.2. Concrete shall consist of approved Portland cement, a fine aggregate of sand, and a coarse aggregate of broken stone or gravel, mixed in the proportions specified for the various classes given below. Samples of all these ingredients shall be submitted to and approved by the Bureau of Tests, and shall be acceptable to the Engineer before being used in the work.

18.3. Concrete will be classified as follows:

First-class concrete shall be made of one part Portland cement, two parts of No. 1 or No. 2 sand (see page 718) and four parts of coarse aggregate.

Second-class concrete shall be made of one part Portland cement, two and one-half parts of No. 2 or No. 3 sand, and five parts of coarse aggregate.

Third-class concrete shall be made of one part of Portland cement, three parts of No. 3 sand, and six parts of coarse aggregate.

quirements of cement for "*Concrete*," and two parts of approved, clean sand mixed with sufficient water to form a plastic mortar.

When corrugated metal pipe sections are to be joined on the work the ends shall be butted together and the sections joined with the band coupler securely bolted in place.

The filling around the pipe shall be made in layers with approved material free from rock and each layer shall be tamped thoroughly around and over the pipe to the elevation of the original ground surface. The material supporting the lower half circumference of the pipe shall be uniformly and securely tamped to give proper support without displacing the pipe.

Payment.—All pipe culverts will be paid for by the linear foot in place at the respective prices bid for the different kinds of pipe. These prices shall be payment in full for all pipe, joint material, etc., and for all labor employed in excavation, backfilling, laying the pipe and filling the joints, but will not include payment for masonry or concrete end walls.

POROUS TILE (NEW YORK STATE SPECIFICATIONS)

Where called for on the plans, or ordered by the engineer, porous tile shall be laid true to line and grade, and firmly bedded in clean cinders, gravel, or crushed stone. The tile must be whole and free from cracks and other defects, and must be satisfactory to the engineer.

TIMBER

(Washington State Specifications)

Quality of Timber and Plank.—All timber and plank in culverts, trestlework, bridge abutments, and pile bridges shall be of good quality, of such kinds as the highway commissioner may direct, free from shakes, wanes, black and unsound knots, and all descriptions of decay, and shall be measured by the thousand feet, board measure; the price shall be understood to cover the expense of all labor (including all necessary digging and filling at the ends of bridges where grading is done before bridges are put in) and materials, pins, or treenails required in the performance of the work.

All timber structures shall be built in conformity with plans to be furnished by the engineer.

Piles and Pile-driving.—Piles, whether used in foundations, trestlework, or pile bridges, shall be of good, sound quality of such timber as the Highway Commissioner may accept, not less than ten inches in diameter at the smaller end and of such lengths as the engineer may require. They shall be measured by the lineal foot after they are driven and cut off to receive the superstructure, and the price per lineal foot shall be understood to cover the expense of driving, cutting off, removing the bark from the part above the ground, and all other labor and material required in the performance of the work; but that portion of each pile cut off shall be estimated and paid for by the lineal foot as "piling cut off." Piles shall be driven of such lengths and to such depths as the engineer may require. All piles shall be capped during the driving to prevent brooming.

LOG CULVERTS (U. S. FOREST ROAD SPECIFICATIONS)

Log culverts shall be constructed in conformity with the plans, or where directed by the engineer.

Materials.—In the construction of log culverts the timber shall be of the species called for on the plans. All knots and projections shall be trimmed down even with the surface of the log, and all bark shall be peeled off before the logs are used.

If Government owned stumpage is available the logs may be cut either from the right-of-way or adjacent Government land, as the engineer may direct, and the engineer will in all such cases indicate the trees to be used, which shall first have been designated by a forest official. The tops and branches of trees shall be disposed of as provided in the specifications for "Clearing and Grubbing," hereinbefore given. The stringer logs shall be straight.

When suitable Government owned stumpage is not available the timber shall be furnished by the contractor at his own expense.

Construction.—The stakes set by the engineer shall control the line and elevation for each structure. If practicable the backfill within and behind the abutments shall be made of stone. Where no stone is available, the logs of the abutment shall be more carefully hewn so as to form close joints that will hold a backfilling of earth. In all cases the logs of the abutments shall be fastened together with five-eighths inch drift bolts.

The stringer logs shall be laid close enough together to hold the fill without leakage and an occasional stringer shall be spiked to the abutment in order to hold the roof of the culvert in place.

The crib wings shall be constructed in the same manner as the abutments.

Where a floor is called for, it shall be constructed of stringer logs and in the manner shown on the plans.

Payment.—Payment for log culverts shall be at the unit bid price per linear foot of culvert measured along the center line of culvert. The bid price for each size of culvert shall be payment in full for all labor and materials entering into any culvert of that size and the necessary excavation and backfilling therefor.

LOG BRIDGES (U. S. FOREST ROAD SPECIFICATIONS)

Log bridges shall be constructed in conformity with the plans or where directed by the engineer.

Materials.—The logs used in constructing log bridges shall be of the species called for on the plans. If Government owned stumpage is available, the logs may be cut either from the right-of-way or adjacent Government land, as the engineer may direct, and the engineer will in all such cases indicate the trees to be used, which shall first have been designated by a forest official. The tops and branches of trees shall be disposed of as provided in the specifications for "Clearing and Grubbing," as hereinbefore given.

When suitable Government owned stumpage is not available the timber shall be furnished by the contractor at his own expense.

The logs shall be straight, sound and free from defects of all kinds and shall be cut from live trees as far in advance of use as possible, but not exceeding one year, and be allowed to season with the bark on. Immediately before use in the work all bark shall be peeled and the logs trimmed smooth of all knots and projections.

All lumber for flooring, railings, etc., shall be of the kind and dimensions indicated on the plans and shall be free from shakes, wanes, black and unsound knots, and from all other defects which would impair its strength in any way.

The contractor shall furnish at his own expense all necessary bolts, drift bolts, spikes, nails and other material or hardware called for on the plans or in the specifications.

Construction.—The contractor shall provide experienced workmen and ample and suitable equipment and tools for performing the work, and shall follow only well recognized methods in preparing the timber and framing and erecting the structure.

Where concrete or masonry piers or abutments are called for on the plans, they shall be constructed in accordance with the requirements of the plans, and of the specifications hereinbefore given for the particular kind of concrete or masonry called for.

Payment.—Each log bridge superstructure complete will be paid for at the price bid per linear foot of bridge, as shown on the plans, which shall include all parts of the bridge except abutments and piers. This amount shall be payment in full for all materials, labor and incidentals, required to construct the bridges in accordance with the plans and specifications.

LOG ABUTMENTS FOR BRIDGES

Log abutments for bridges will be built according to the specifications for "Log Cribbing," and as shown on the plans, and will be paid for as "Log Cribbing."

LOG CRIBBING (U. S. FOREST ROAD SPECIFICATIONS)

Log cribbing shall be built to the lines and grades given by the engineer and constructed in conformity with the plans or as directed by the engineer.

foundation for pavement or concrete pavement shall be laid when the temperature falls below 35 degrees Fahrenheit.

18.18. All damage to or disfigurement of concrete of any kind occurring prior to the final acceptance of the work shall be remedied by the Contractor at his own expense and to the satisfaction of the Engineer.

18.19. No piece of stone shall be left within one inch of any face, a broad-tined fork or other implement, if approved, being thrust between the form and the concrete to pry the fragments of stone back from the face.

The top surface of concrete shall be formed immediately after the underlying course is completed and before this course takes its initial set. The top surface shall be formed by cutting off the excess with a template and shall then be rubbed smooth and hard with a wooden float by skilled men. As soon as the concrete has sufficiently set and the Engineer shall so direct, the forms shall be removed and all exposed faces immediately finished by being rubbed smooth with a mortar block and water. No plastering of any surface will be allowed, the required finish being obtained by rubbing down the irregularities of the face. All exposed surfaces shall be smooth, dense, without pits, irregularities, blow holes or bubbles. The surface of all finished and unfinished work shall be kept wet for a period of six days unless otherwise directed by the Engineer.

All edges, joints of sections and angles which will be exposed in the finished structure shall be rounded. A radius of one inch shall be used unless otherwise designated on the plans or directed by the Engineer.

18.20. Concrete shall not be laid in water nor exposed to the action of the water before setting, except by written permission of the Engineer, and then in such manner as he may specially direct.

18.21. Where concrete is to rest on any excavated surface other than rock, special care shall be taken not to disturb the bottom of the excavation, and the final removal of material to grade shall not be made until just before the concrete is laid, except in concrete foundations for pavement.

The excavation lines and bases of structures shown on the plans shall be considered as only approximate; and they may be ordered in writing by the Engineer, to be placed at any elevation or of any dimensions that will give a satisfactory foundation. Any additional concrete that may be required by the Engineer below or beyond the lines shown on the plans will be paid for at the contract price.

No structure shall be commenced without the Engineer's approval.

All rock or hardpan foundation surfaces shall be freed from loose pieces, cut to firm surfaces and cleaned to the satisfaction of the Engineer, before laying concrete. All seams shall be cleaned out and filled with concrete or mortar; and payment for such cleaning out and filling shall be made at the contract price for the class of concrete used.

18.22. The quantity to be paid for under Items 18, 19 and 20 shall be the number of cubic yards of the various classes measured in place in the finished structures placed in accordance with the plans or as ordered by the Engineer. No payment will be made for any concrete outside of these limits, nor for any concrete whose placing is rendered necessary owing to lack of proper care.

The price bid for Items 18, 19 and 20, respectively, shall include all materials, forms, labor and other incidental expenses necessary to satisfactorily complete the work as specified in the foregoing paragraphs for first-class concrete, second-class concrete and third-class concrete respectively.

Item 21—Stone Masonry

21.1. Under this item the Contractor shall furnish and build all stone masonry in structures or elsewhere, as shown upon the plans or ordered by the Engineer.

21.2. Stone masonry shall be built of clean stone, free from structural defects, laid in full cement mortar beds. Selected stone, roughly squared and pitched to line, shall be used at all angles and ends of walls.

21.3. The stone shall be laid on its natural bed to form substantial masonry, presenting a neat and finished appearance. Spalls and pinners shall not be allowed to show on the face of the wall, and shall be used only where necessary. The length of stretchers shall not exceed three times their rise; the width of stretchers shall in no case be less than their rise. At least one-fourth of the stone in the face shall be headers, and these shall be evenly

istributed; the length of headers shall not be less than the thickness of he wall, where the wall is four feet or less in thickness; where the wall is iore than four feet in thickness, the length of the headers shall not be ss than two feet and eight inches, and not more than two-thirds of the iickness of the wall; the width of the headers shall not be less than their se. All stones shall be laid to break joints six inches or more and to ioroughly bond the work. No joint of the face shall be over one inch in idth. Backing shall consist of good-sized, well-shaped stone so laid as break joints. All spaces between the stone shall be filled with spalls it in mortar. The rear faces shall present approximately plain surfaces.

21.4. End walls of culverts and retaining walls shall be capped with oncrete or with stone, roughly squared, extending across the entire width f the wall, and on steps of wing walls the coping shall extend under the ep next above it at least eight inches.

21.5. On all exposed faces, the joints shall be raked out and cleaned a depth of two inches and then pointed with Portland cement mortar iixed in a proportion of one to one.

21.6. The quantity of stone masonry to be paid for under this item shall e the number of cubic yards measured in the completed work, and the mits shall not exceed those shown upon the plans or fixed by the Engineer. The price bid shall include all labor, materials and incidental expenses ecessary to satisfactorily complete the work.

Item 22—Stone Curbing and Headers

22.1. Under this item the Contractor shall furnish and place stone curbing nd headers where shown on the plans or ordered by the Engineer.

22.2. Stone curbing and headers shall be of approved bluestone, sand-one or granite, sound, uniform, free from seams or other imperfections, and iall be nowhere less than 5 inches thick, 15 inches deep, and 3 feet long. The upper face shall be evenly cut and the front face shall be dressed r the full depth to an even surface with no projections or depressions ex-eding one-quarter inch. The bottom shall be roughed off parallel to the p so that there will be no projections exceeding 2 inches beyond the quired depth.

The ends shall be squared and dressed to form joints not exceeding one-ghth inch for a depth of at least 2 inches from top and front face. The acks shall be rough dressed for full depth and dressed the same as the ce for a depth of 2 inches from the top. The joints of circular curbing iall be cut on radial lines.

22.3. The curb or header shall be set in third-class concrete, as shown the plans. It shall be true to line and grade and settled so as to have a rm and uniform bearing.

22.4. If required by the plans, porous drain-tile shall be placed under one curbing and firmly embedded and covered with cinders, gravel or oken stone.

22.5. After the curb or header has been set the trenches shall be filled ith earth and thoroughly tamped.

22.6. The quantity to be paid for under this item shall be the number linear feet of curbing or headers set in accordance with plans and directions the Engineer.

The price bid for this item shall include the furnishing and setting of e curb or header, all concrete, tile, broken stone or gravel, and all labor, aterials and incidental expenses necessary to complete the work.

Item 23—Resetting Old Curbing

23.1. Under this item the Contractor shall remove and reset old curbing, shown upon the plans or ordered by the Engineer.

23.2. Care shall be taken in removing old curbing so that there shall be unnecessary breakage, and any curbing damaged in removing, hauling, storing, due to the carelessness of the Contractor, shall be replaced with w curbing at his own expense.

23.3. All joints and tops shall be redressed, if directed by the Engineer, obtain a smooth top surface and to obtain joints of the same class as ecified for new curbing.

23.4. The quantity to be paid for under this item shall be the number of linear feet removed, stored, hauled, and reset in accordance with the plans and as directed by the Engineer.

The price bid shall include all concrete, tile, removing, redressing, hauling, storing, resetting, and all materials, labor and incidental expenses necessary to complete the work.

Item 24—Concrete Curbing

24.1. Under this item the Contractor shall place concrete curbing, of the type shown on the plans, where shown on the plans or ordered by the Engineer.

24.2. All curbing shall be constructed of first-class concrete. The concrete shall be of such consistency, and be so spaded and worked, that a smooth mortar face will be produced. The coarse aggregate for concrete curbing shall be approved No. 2 stone or gravel.

24.3. Curbing shall be moulded in place in sections 6 feet long and provision made at each joint for expansion of one-sixteenth inch.

24.4. All forms shall be set true to line and grade and held rigidly in position. They shall be either of metal or of acceptable planed and matched lumber, and of such construction that a smooth surface will be provided.

The forms shall be left in place until the concrete has set sufficiently so that they can in the opinion of the Engineer be removed without injury to the curbing. The curbing shall immediately upon the removal of the forms be rubbed down to a smooth and uniform surface, but no plastering will be allowed. For this work a competent and skillful finisher shall be employed.

24.5. The Contractor shall protect the curbing and keep it in first-class condition until the completion of the contract. Any curbing which is damaged at any time previous to the final acceptance of the work shall be removed and replaced with satisfactory curbing at the Contractor's expense. (Also see section 18.1.)

24.6. The quantity to be paid for under this item shall be the number of linear feet placed in accordance with the plans or directions of the Engineer.

The price bid for concrete curbing shall include the furnishing and placing of all concrete, tile, porous filling, forms, and all other materials, labor and incidental expenses necessary to complete the work.

Item 25—Concrete Edging

25.1. Under this item the Contractor shall furnish and mould in place concrete edging of the type shown on the plans and where designated on the plans or ordered by the Engineer.

25.2. The concrete edging shall be composed of second-class concrete. The top shall be troweled to an even surface and the material shall be rammed and spaded so that a dense concrete and a smooth surface will result. (Also see section 18.1.)

25.3. The forms shall be set and held true to line and grade, and shall not be removed until the concrete has set sufficiently, in the judgment of the Engineer, so that no harm will result therefrom. The edging shall be protected from injury until the completion of the contract.

After the removal of the forms, the trenches shall be back-filled with earth and thoroughly tamped.

25.4. The quantity to be paid for under this item shall be the number of linear feet of concrete edging completed as shown on the plans or ordered by the Engineer.

The price bid shall include the furnishing and placing of concrete and forms, and all other materials, labor and incidentals necessary to complete the work.

Item 26—Cobble Gutters

26.1. Under this item the Contractor shall furnish and place cobble gutters where shown on the plans or ordered by the Engineer.

26.2. Cobble gutters shall consist of rounded "hardheads," quarry or field stone, and shall be laid on edge. If hardheads are used they shall be 4 inches to 8 inches in diameter. The largest stones shall be selected

and set along the edges of the gutter. All stones except where embedded in mortar shall be set in sand, and shall be laid to line and grade with close joints by skilled workmen using regular paving tools. The whole shall then be thoroughly rammed in place and brought to a uniform surface. All joints shall be swept full of sand. On grades exceeding 6 per centum and elsewhere if called for by the plans or ordered by the Engineer, cobble gutters shall be laid in Portland cement mortar, mixed one to three, as shown upon the plans.

26.3. The quantity of cobble gutter to be paid for under this item will be the number of square yards of exposed surface laid in accordance with the plans and as directed by the Engineer.

The price bid shall include the furnishing and placing of all stones, sand, mortar, and all other materials, labor and incidental expenses necessary to complete the work.

Item 27—Concrete Gutters

27.1. Under this item the Contractor shall furnish and place concrete gutters where shown upon the plans or ordered by the Engineer.

27.2. Concrete gutters shall be of first-class concrete and shall conform to all requirements therefor as elsewhere specified. They shall be of the shape and length shown upon the plans, and shall be placed true to line and grade as directed. (See section 18.1.)

27.3. The quantity for which the Contractor will be paid shall be the number of square yards of concrete gutters placed in accordance with the plans and ordered by the Engineer.

The price bid shall include the furnishing and placing of all concrete, the preparation of foundation, together with all other labor and incidental expenses necessary to satisfactorily complete the work.

Item 28—Brick Gutters

28.1. Under this item the Contractor shall furnish and place brick gutters where shown upon the plans or ordered by the Engineer.

28.2. Brick gutters shall be constructed of approved brick, shall conform to the dimensions shown upon the plans, and shall be laid true to lines and grades upon a suitable bed of sand.

28.3. Where brick gutters are to be laid next to a curbing in connection with a pavement having a concrete foundation, they shall be constructed in full conformity to the specifications for brick pavement, and shall be paid for as such.

28.4. The quantity for which the Contractor will be paid shall be the number of square yards of brick gutters placed in accordance with the plans and ordered by the Engineer.

The price bid shall include the furnishing and placing of all materials and the preparation of bed, together with all other labor and incidental expenses necessary to satisfactorily complete the work.

Item 29—Metal Reinforcement

29.1. Under this item the Contractor shall furnish and place metal bar and metal mesh reinforcing material where shown upon the plans or directed by the Engineer.

29.2. All metal reinforcement shall, when embedded, be free from mill scale, grease, injurious rust, dirt or other foreign substance.

29.3. All metal reinforcement shall be securely held in place so that it will be in the prescribed position after the concrete has been thoroughly compacted.

29.4. Unless otherwise designated upon the plans, all bar reinforcement shall be of open hearth steel, and shall consist of approved "deformed" bars or rods which shall have an elastic limit of not less than 30,000 nor more than 45,000 pounds per square inch, and an elongation of not less than 20 per centum in a length of 8 inches.

Deformed bars shall not contain more than 5/100 of one per centum of sulphur nor more than 4/100 of one per centum of phosphorus. In small culverts and other structures of minor importance standard commercial deformed bars acceptable to the Engineer may be used.

All deformed bars shall be uniform in quality, and shall endure bending

180 degrees, when cold, around a circle whose diameter is equal to the diameter or thickness of the test piece, without fracture on the outside of the bent portion.

Bars shall overlap each other by 30 diameters.

29.5. Unless otherwise designated upon the plans, all metal mesh reinforcement shall be of an approved kind and quality, and of the cross-section shown upon the plans and acceptable to the Engineer, and equal in all respects to the best standard commercial products. Sheets of metal mesh shall overlap each other as directed by the Engineer or as shown upon the plans.

29.6. The quantity of metal reinforcement for which the Contractor will be paid shall be the number of pounds incorporated in the work in accordance with the plans or directions of the Engineer.

The bid price shall include all labor, materials, and other expenses necessary to satisfactorily complete the work.

Metal reinforcement used in rails and posts shall not be included in this item, but shall be considered as being included in the price bid for appropriate items.

Item 30—Miscellaneous Iron and Steel

30.1. Under this item the Contractor shall furnish and place all cast iron, wrought iron and steel not especially included in other items as shown on the plans and for miscellaneous structures as ordered by the Engineer. This item shall include beams, channels, and other structural shapes, as well as miscellaneous iron castings, wrought iron, etc.

30.2. All structural steel, bolts, etc., shown on the plans may be of stock steel. Stock steel shall be subjected only to surface inspection and cold bending tests. Test pieces cut from finished materials shall endure bending cold, without signs of cracking, 180 degrees around a circle whose diameter is equal to the thickness of the test piece.

Iron castings shall be made of the best tough gray iron of uniform quality and shall be free from defects and uneven shrinkage. No mill cinder iron, white or burnt iron or scrap of any kind shall be used. They shall be clean, out of wind, and true to dimensions. Castings having blow holes plugged or filled with putty or crust shall not be used.

Wrought iron shall be tough, fibrous and uniform in quality and shall be manufactured by approved methods. Steel scrap shall not be used in its manufacture. Finished material shall be clean, smooth, true to shape and free from defects.

All iron and steel except cast iron shall be given a shop coat of red lead and oil, and after being placed shall be given two coats of approved paint.

30.3. The quantity of iron, wrought iron and steel to be paid for under this item shall be the number of pounds furnished and placed in accordance with the plans or instructions of the Engineer. The price bid shall include the furnishing, placing, painting and all other labor, materials and incidental expenses necessary to satisfactorily complete the work.

Item 31—Wooden Guard Railing

31.1. Under this item the Contractor shall furnish and erect wooden guard railing of the type indicated, where shown on the plans or ordered by the Engineer.

31.2. The posts shall be of seasoned white oak, cedar, locust, tamarack, white pine, or chestnut. They shall be at least 6 inches square, or if round they shall be 6 inches in diameter at the smaller end after the bark is removed, and 7 feet long. Round posts shall be shaved to even surfaces free from bark or skin. The lower part of the posts to a point 3 feet from the top shall be dipped while dry in suitable bituminous material heated to a temperature of 300 degrees Fahrenheit, or shall be charred as directed. The posts if dipped shall be thoroughly dry before being set in the ground.

31.3. Rails shall be of seasoned, planed spruce or other satisfactory wood, and be properly secured to the posts, all in a workmanlike manner.

31.4. The joints of the rails and posts shall be given one coat of white lead and linseed oil before being put together; the beveled tops of posts shall receive two heavy coats of the same. The entire surface exposed above the ground shall be painted with three coats of white lead and linseed oil.

31.5. The white lead and the linseed oil shall be delivered separately on the road in original containers; before being mixed and used a pint sample of each, covering each lot, shall be forwarded to the Bureau of Tests, and neither ingredient shall be used until accepted by the Commission. The mixing of the ingredients shall be as directed by the Engineer. This specification shall apply to all paint used under this contract.

31.6. The quantity of wooden guard railing to be paid for under this item shall be the number of linear feet completed in place.

The price bid shall include the furnishing and erecting of all posts and rail, the excavation, painting, dipping, hardware and all expenses and incidentals necessary to complete the work.

Item 32—Special Guard Railing

32.1. Under this item the Contractor shall furnish and erect, true to line and grade, guard railing of the special design shown upon the plans, at the places indicated by the plans or ordered by the Engineer.

32.2. Except as otherwise provided by the plans, each class of work necessitated under this item shall be governed by the clauses of other items which are specially applicable thereto.

32.3. The quantity of guard railing to be paid for under this item shall be the number of linear feet placed in accordance with the plans and ordered by the Engineer.

The price bid shall include all excavation, concrete, metal reinforcement, hardware, backfilling and all other materials, labor and incidental expenses necessary to satisfactorily complete the work.

Item 33—Pipe Railing

33.1. Under this item the Contractor shall furnish and erect pipe railing of the type indicated where shown upon the plans or ordered by the Engineer.

33.2. Pipe railing shall consist of wrought iron pipe, rails, posts and pipe rail fittings of the sizes shown on the plans. All threaded joints shall be coated with lead and oil before being assembled. All parts shall be painted, after being put in place, with two coats of white lead and linseed oil.

33.3. The quantity of pipe railing to be paid for under this item shall be the number of linear feet placed in accordance with the plans and ordered by the Engineer.

The price bid shall include the furnishing and erecting of all materials, the painting and all expenses and incidentals necessary to complete the work.

Item 34—Guide Signs

34.1. Under this item the Contractor shall furnish and erect guide signs of the type indicated where shown upon the plans or ordered by the Engineer.

34.2. Permanent guide signs shall be for the purpose of furnishing permanent directions to traffic after the completion of the contract. Permanent guide signs shall be constructed of kiln dried white pine and of the dimensions shown on the plans. They shall first be given four coats of white lead mixed with linseed oil. After the last coat has become thoroughly dried the letters shall be painted with black enamel paint, and when this is thoroughly dry they shall be given one coat of the finest white shellac.

34.3. Temporary guide signs shall be for the purpose of guiding traffic along a detour during construction. Temporary guide signs shall be constructed of kiln dried white pine and of the dimensions shown on the plans. They shall first be given three coats of white lead mixed with linseed oil. After the last coat has become thoroughly dried the letters shall be painted with black enamel paint.

34.4. The number of guide signs to be paid for under this item shall be the number of signs placed in accordance with the plans and ordered by the Engineer. All signs become the property of the State upon payment for this item.

The price bid shall include the furnishing of all labor and materials necessary to satisfactorily erect permanent guide signs on sign posts and temporary guide signs including sign posts, each guide sign complete in place.

Item 35—Highway Number Signs

35.1. Under this item the Contractor shall paint on the concrete sign post highway number signs of the type indicated where shown upon the plans or ordered by the Engineer.

35.2. Highway number signs shall be painted on all concrete sign posts with letters which shall first be formed of two coats of flat black mixed in oil and afterward retraced with black enamel.

35.3. The number of highway number signs to be paid for under this item shall be the number placed in accordance with the plans and ordered by the Engineer.

The price bid shall include the furnishing of all labor and materials to satisfactorily complete the work.

Item 36—Danger Signs

36.1. Under this item the Contractor shall furnish and erect danger signs where shown upon the plans or ordered by the Engineer. These shall be of the type called for by the plans.

36.2. Danger signs shall be constructed of a material and painted similar to that specified for guide signs and shall be of the dimensions and lettered as shown on the standard plans. These signs shall be placed on the standard concrete sign posts and set at an angle of forty-five degrees to the center line. When the standard sign is used the arrow shall point in the direction of the danger.

36.3. The number of completed danger signs for which the Contractor will receive payment will be the number placed in accordance with the plans and ordered by the Engineer.

The price bid shall include the furnishing of all labor and materials necessary to complete each danger sign in a satisfactory manner.

Item 37—Concrete Sign Posts

37.1. Under this item the Contractor shall furnish and erect concrete sign posts of the type indicated, where shown upon the plans or ordered by the Engineer.

37.2. Concrete sign posts shall be made of first-class concrete and of the dimensions and materials shown on the standard plans. To these posts shall be securely fastened guide boards and signs.

37.3. The number of completed concrete sign posts to be paid for under this item shall be the number erected in accordance with the plans and ordered by the Engineer.

The price bid shall include all concrete, reinforcement, forms, excavation and backfill, and the furnishing of all other labor and materials necessary to complete each concrete sign post in a satisfactory manner.

LOOSE STONE

Item 38—Screened Gravel—Loose Measure

Item 39—Broken Stone—Loose Measure

38.1. Under these items the Contractor shall furnish and place upon the road, as directed by the Engineer, broken stone and gravel of the sizes designated on the Itemized Proposal. This stone and gravel will be used for general repair work and for miscellaneous work.

38.2. The stone or gravel delivered shall be of approved quality and shall conform to the general requirements for broken stone and gravel, and they shall be of the sizes ordered.

38.3. The quantity to be paid for under Items 38 and 39 respectively shall be the quantity of broken stone or gravel furnished and delivered on the work at the places and in the condition specified by the Engineer. When the material is produced by the contractor on the work, it shall be measured in cubic yards; it shall be measured in tons of 2000 lbs. when the material is imported and the weight is obtainable from reliable sources such as certified quarry or railroad figures.

The price bid shall include furnishing and delivering the stone or gravel

as directed by the Engineer and all labor, appliances and expenses incidental thereto; also the spreading, rolling or incorporating of the stone or gravel in the work, when required by the Engineer.

FOUNDATION COURSE

Item 40—Foundation Course—"Run of Bank" Gravel

Item 41—Foundation Course—Field or Quarry Stone

40.1. Under these items the Contractor shall furnish and place a foundation course of stone or gravel of the depth and in the places called for by the plans, or as ordered by the Engineer in accordance with section 2.5, "Preparation of Subgrade" of item "Excavation."

40.2. No stone or gravel shall be placed on the road until the culverts are completed and proper drainage provided.

40.3. When field or quarry stone is used for constructing the foundation course it shall be of a hard, sound and durable quality, acceptable to the Engineer; the stones shall be placed by hand so as to bring them in as close contact as possible. When quarry stones are used they shall be placed on edge. The depth of the stone shall in no case be greater than the depth specified for the course, the width shall not be greater than the depth, nor more than six inches; and the length shall not be greater than one and one-half times the depth, nor more than 12 inches. The distribution of the stone shall be of a uniformity satisfactory to the Engineer. The long dimension shall always be placed crosswise the road. After laying, this course shall be thoroughly rolled with an approved roller weighing not less than ten tons, and shall then be filled with stone or gravel as directed and again rolled until the stones are bound together and thoroughly compacted; but no gravel shall be used for filling except under written permission of the Engineer. All holes or depressions found in rolling shall be filled with material of the same quality and the surface shall be re-rolled until it conforms to the lines and grades shown on the plans. When field stone is used approved tailings may be used for filling. In all cases a sufficient amount of fine material shall be used to fill all voids. In limited areas where the use of a roller is impracticable heavy tampers may be used to consolidate the material.

40.4. Wherever gravel is used for the foundation course it shall conform in all particulars to the gravel specified in section 2 of BOTTOM COURSE "RUN OF BANK" GRAVEL.

40.5. The quantity to be paid for under this item shall be the number of cubic yards of compacted material in place. The amount to be estimated shall be computed by multiplying the finished cross-section of the foundation course as shown upon the plans or ordered by the Engineer, by the length of the foundation course measured along the axis of the pavement.

The price bid shall include the furnishing, placing, filling, rolling of the material and all labor and incidental expenses necessary to complete the work.

Item 42—Foundation Course—Telford Base

42.1. Under this item the Contractor shall furnish and place a foundation course of field or quarry stone laid on edge, in accordance with the plans or as ordered by the Engineer.

42.2. No stone shall be placed on the road until the culverts are completed and proper drainage has been provided.

42.3. Field or quarry stone of approximate rectangular shape shall be used. The stone shall be not less than one and one-half inches thick, in depth equal to the depth of the course, and in length not more than one and one-half times the depth.

42.4. The pieces shall be placed on edge by hand in as close contact as possible with long dimension crosswise of the road. After being placed, all pieces projecting more than one inch above the established plane of the surface shall be broken off flush so as to obtain a true and uniform surface. This course shall then be rolled with an approved self-propelled roller weighing not less than ten tons, and shall then be filled with approved screenings and again rolled until the course is thoroughly compacted. Material other than screenings for filling this course shall not be used except under the written order of the Engineer.

42.5. The quantity to be paid for under this item shall be the number of cubic yards of compacted material in the completed course. The amount to be estimated shall be computed by multiplying the finished cross-section of the foundation course as shown upon the plans or ordered by the Engineer, by the length of the foundation course measured along the axis of the pavement. The price bid shall include the furnishing, placing, filling, rolling of the material and all labor and incidental expenses necessary to complete the work.

BOTTOM COURSE

Item 43—"Run of Bank" Gravel

43.1. Under this item the Contractor shall furnish and place approved "Run of Bank" gravel either upon the properly prepared sub-grade or upon the foundation course. The work shall be performed in full conformity to the specifications given under sections 44.2 to 44.9 inclusive, so far as same are not inconsistent with the use of such gravel.

43.2. All gravel shall be of hard, durable stone satisfactory to the Engineer. The particles shall be of such size as will pass through a 3½-inch circular hole, and shall be well graded. Gravel shall be of such nature that the material passing a ¼-inch screen shall not be more than 5 per[1] centum in excess of the voids in the remaining material after its separation therefrom. Before using "Run of Bank" gravel in the work the same shall be tested to determine its suitability. Should at any time during the work and for any reason the gravel fail to maintain suitable proportions of the coarse and fine particles, the Contractor shall by the addition of selected material and satisfactory manipulation produce a material meeting the above requirements.

43.3. The depth of loose stone or gravel in all cases, whether in foundation, bottom or top courses, shall be gauged by the use of cubical blocks of suitable size. (See page 591.)

43.4. The spreading of any layer or course of broken stone, gravel or filler, whether in foundation, bottom or top courses, shall be done from suitable spreader wagons or from piles dumped along the road as directed by the Engineer.

No segregation of large or fine particles will be allowed, but the stone as spread shall be well graded with no pockets of fine material.

43.5. The quantity to be paid for under this item shall be the number of cubic yards of compacted material in place in the completed course. The amount to be estimated shall be computed by multiplying the finished cross-section of the bottom course as shown on the plans or ordered by the Engineer, by the length of the bottom course measured along the axis of the pavement.

The price bid shall include the furnishing, placing, rolling and filling the material, and all other labor, materials and incidental expenses necessary to satisfactorily complete the work.

Item 44—Bottom Course—Screened Gravel

Item 45—Bottom Course—Broken Stone

44.1. Under these items the Contractor shall furnish and place stone or gravel, conforming to the general requirements for same, either upon the properly prepared sub-grade or upon the foundation course. This stone or gravel shall be of sizes specified below.

44.2. After the sub-grade or foundation course shall have been properly prepared and proper drainage provided, a course of broken stone or gravel of graded No. 3 or No. 4 or a uniform mixture of same shall be spread evenly so that it will have after rolling the required thickness. If specifically allowed by the Engineer a limited amount of No. 2 stone may be used in the bottom course. (For the meaning of these numbers in connection with size see page 720).

In cases where the finished thickness of the bottom course is to be more than 5 inches, the broken stone or gravel for it shall be spread, rolled and filled in two separate layers neither of which shall be of a greater depth than 6 inches measured loose.

[1] Not feasible, see page 156.

44.3. The depth of loose stone or gravel in all cases, whether in foundation, bottom or top courses, shall be gauged by the use of cubical blocks of suitable size. (See page 591.)

44.4. The spreading of any layer or course of broken stone, gravel or filler, whether in foundation, bottom or top courses, shall be done from suitable spreader wagons or from piles dumped along the road as directed by the Engineer.

No segregation of large or fine particles will be allowed, but the stone spread shall be well graded with no pockets of fine material.

44.5. After the bottom course of stone or gravel has been laid loose it shall be thoroughly rolled with an approved roller weighing not less than ten tons.

This rolling must begin at the sides and continue toward the center and shall continue until there is no disturbance of the stone ahead of the roller. After the stone is thoroughly compacted No. 1 stone or gravel, and screenings or sand, or a mixture of these, shall be uniformly spread upon the surface and swept in with rattan or steel brooms and rolled dry. After the completion of the rolling no teaming other than that necessary for bringing material for the next course shall be allowed over the rolled material. It is the intention to bind this course with the small stone, but not to use so much that a good bond will not be secured between the bottom and top courses.

44.6. When two courses of bottom stone are laid each course shall be treated by rolling and adding fine material as described above.

44.7. If the sub-grade material shall become churned up into or mixed with the bottom or sub-bottom courses through the Contractor's hauling over it or working on it when the sub-grade is in a wet condition, the Contractor shall at his own expense remove such mixture of sub-grade material and broken stone and replace it with clean broken stone of the proper size, and shall roll or otherwise compact the material so as to produce a uniform, firm and even bottom course.

If the above condition occurs through no fault of the Contractor, the Contractor shall be paid both for excavating and replacing under the items "Excavation" and "Bottom Course" respectively.

44.8. All filler for top and bottom courses shall be delivered and piled alongside the road before the course in which it is to be used is placed.

44.9. The quantity to be paid for under these items respectively shall be the number of cubic yards of compacted material in place in the completed course. The amount to be estimated shall be computed by multiplying the finished cross-section of bottom course as shown upon the plans or ordered by the Engineer, by the length of the bottom course measured along the axis of the pavement.

The price bid for the respective items shall include the furnishing, placing, filling, rolling of the material and all labor and incidental expenses necessary to complete the work.

Item 46—Concrete Foundation for Pavement

46.1. Under this item the Contractor shall furnish and place upon a propery prepared sub-grade, concrete foundation for pavement of the thickness shown upon the plans or ordered by the Engineer.

46.2. Concrete foundation shall not be placed on any sub-grade until the sub-grade has been properly drained, thoroughly rolled and compacted, and is true to line and grade in horizontal and transverse cross-section.

46.3. Concrete shall consist of a mixture of Portland cement, No. 2 or No. 3 sand and broken stone or gravel. The coarse aggregate shall consist of a well-mixed product of No. 2 and No. 3 stone or No. 2 and No. 3 gravel. The fine aggregate shall consist of No. 2 or No. 3 sand. All of these materials shall conform in all respects to the requirements given under "Materials of Construction," pages 717 to 720. All specifications relating to second-class concrete shall apply to work done under this item, in so far as they are not inconsistent with the special specifications given below.

46.4. The concrete shall be mixed in the proportions of one volume of cement to two and one-half volumes of sand and five volumes of broken stone or gravel. The relative proportions of fine and coarse aggregate may be varied slightly, as a result of tests for voids by the Engineer, to

the end that the resulting concrete shall be as dense as possible. The concrete shall in all cases approximate a 1 : 2½ : 5 mix.

46.5. The concrete shall be mixed in approved mechanical batch mixers. Mixing shall be continued through at least 12 revolutions and until every particle is coated with mortar and until the batch is of uniform color and consistency. After the materials are once wetted the work shall proceed rapidly until the concrete is in place. The quantity of water used shall be as directed by the Engineer and suitable measuring tanks shall be provided by the Contractor so that the same amount of water may be used in the separate batches.

46.6. Before any concrete is placed, the sub-grade shall be sprinkled sufficiently to dampen it, but a muddy condition shall not be allowed. As soon as possible after mixing, the concrete shall be deposited in place and thoroughly spaded and rammed so as to bring the mortar flush to the surface. Especial care shall be taken to keep the concrete uniform and to prevent pockets of stone or mortar.

46.7. The surface, when completed, shall conform to the lines and grades shown upon the plans, and shall be free from depressions or irregularities. No stone shall project above the general surface. All ramming and shaping shall be done before the concrete has taken its initial set.

46.8. When the work is stopped for any reason a vertical joint shall be put in and the work completed up to this joint.

46.9. No concrete foundation for pavement shall be laid when the temperature falls below 35° F.

46.10. As soon as the concrete has taken its initial set the surface shall be covered with a one-inch layer of suitable material and this shall be kept moist for a period of at least seven days. For covering concrete foundations on which a sand cushion is called for, the sand cushion may be used for the cover coat if the contractor so elects; in case this is done the sand cushion shall be put in acceptable condition before preparing for laying the blocks; any portions which have become excessively dirty shall be removed and replaced with acceptable material to the satisfaction of the Engineer.

In those cases where material other than sand cushion is used as a cover coat it shall be cleaned off after a period of ten days.

46.11. The quantity to be paid for under this item shall be the number of cubic yards of concrete foundation for pavement incorporated in the work in accordance with the plans or as directed by the Engineer.

The price bid shall include the furnishing and placing of all materials; all mixing, tamping, finishing, and all labor, appliances and incidental expenses necessary to complete the work. The amount to be estimated shall be computed by multiplying the cross-section of concrete foundation as shown upon the plans or ordered by the Engineer by the total length of concrete foundation measured along the axis of the pavement.

Series of 1917

IOWA STATE HIGHWAY COMMISSION

AMES, IOWA

Standard Specifications For Earth and Gravel Road Construction

Revised series of 1917 distributed by the State Highway Commission under Chapter I-A, Title VIII, Supplement to the Code 1913 as amended by Acts of the Thirty-Sixth General Assembly

Section Three

EARTH ROADS

1. **Alignment.**—The center of the finished roadway shall conform in alignment to the center stakes. These stakes shall follow, as nearly as possible, the center line of the right-of-way.

2. **Grade Lines.**—The grade line shown on the profiles shall denote the crown of the finished roadway at its center line.

3. **Cross-section.**—Unless otherwise provided the cross-section to be used is the standard cross-section of the Highway Commission for the road system on which the work is located.

NOTE.—The Commission will approve changes in the standard cross-section to meet local conditions, on specific improvements, but a change approved for one road shall not be construed to apply to other roads. In each case the proposed change should be submitted to the district engineer who will make a field examination to determine the feasibility of the changes proposed.

4. **Grading.**—Under this head will be included all excavation and embankments required for the formation of the earth roadway, cutting all ditches along or contiguous to the road, forming the approaches to all side roads and farm entrances, changing of stream channels, and all other excavations and embankments connected with or incident to the construction of the road. Grading will be estimated under the following heads, viz.:

Solid rock excavation.
Loose rock excavation.
Earth excavation.

Solid rock excavation will include all rock in masses which can not be removed without blasting, also all detached rock or boulders measuring not less than one cubic yard each.

Loose rock excavation will include all slate or other rock which can be quarried or removed without blasting, also all detached rock or boulders measuring not less than one-fourth nor more than one cubic yard each.

Earth excavation will include all loose stones, boulders, and other material of every description as found, which are not included in the above specifications as solid and loose rock.

5. **Excavation.**—Excavation shall be made in all cases to the required alignment and cross-section. Any roots, stumps, or other timber encountered in the excavation shall be removed and burned or otherwise disposed of as directed by the engineer, but shall not be placed in the embankments. All materials taken from excavations shall be deposited in the embankments unless otherwise specified or directed by the engineer. The cost of moving the same when the average length of haul does not exceed five hundred (500) feet will be considered as included in the price per cubic yard for excavation.

6. **Provision for Drainage.**—If it is necessary in the prosecution of the work to interrupt or obstruct the natural drainage of the surface, or the flow of artificial drains, the contractor shall provide for the same during the progress of the work in such a way that no damage shall result to either public or private interests. He shall then be held liable for all damages which may result from any neglect to provide for either natural or artificial drainage which he may have interrupted.

7. **Intercepting Ditch.**—In cuts along sidehills where there is a possibility of surface water causing damage by flowing down the side slope of the cut, a ditch shall be constructed to intercept the surface water and prevent it from flowing into the cut. The contractor will be paid for this work as an extra.

8. **Borrow Pits.**—When sufficient material for the embankments is not obtainable within the side ditches and excavations as staked out, the contractor shall make up the deficiency from borrow pits laid out by the engineer. Borrowing must be done from regular shaped borrow pits in order to admit of ready and accurate measurements, care being taken not to unnecessarily injure or disfigure the land. The banks must be sloped, the pits so constructed that surface water will drain out and the premises left in a condition satisfactory to the engineer. The right-of-way for borrow pits will be furnished by the county.

9. **Berms.**—Wherever it becomes necessary to make an excavation along the side of the road as in the construction of borrow pits, ditches, etc., a berm not less than four feet in width shall be left between the toe of slope of the roadway embankment and the top of the excavation bank.

10. **Waste.**—When the amount of cut exceeds the amount of fill the excess material shall be deposited as direoted by the engineer. Such material shall preferably be used in widening the adjacent fills so as to reduce the side slopes thereon.

11. **Embankments.**—Embankments shall be carried up in horizontal layers, each of which shall be carried out to its proper width in the cross-section of the roadway. Sod obtained in the cuts may be deposited in the embankments provided it is so placed as to be not closer than twelve (12) inches to the finished roadway or subgrade. Stones obtained from cuts shall be so distributed in the embankments as to not form pockets or cavities. All existing slopes and surfaces of embankment shall be plowed where additional fill is to be made, so that the new material will bond with the old.

12. **Guard Rail.**—Where the height of an embankment is over six feet, substantial guard rails shall be constructed along the shoulders. Such guard rail will be paid for at the price bid per lineal foot of rail. Where the height of the embankment is six feet or less, the side slopes shall be flattened to a slope not steeper than three to one (3 : 1) unless otherwise shown on the plans.

13. **Sod in Blade Grader Work and Shallow Fills.**—In blade grader work and in fills so shallow that the sod cannot be kept at least twelve (12″) inches below the finished roadway, such sod, after being cut loose with blade grade or plows, shall be disked and harrowed until it is reduced to small pieces which will not interfere with traffic. These small pieces of sod shall not be deposited in the middle of the road but shall be deposited near the shoulders and shall be covered with earth. The middle portion of the road shall be formed of earth free from sod. The disking and harrowing of sod is included in the price bid for excavation.

14. **Side Ditches.**—The side ditches shall be excavated to the depth, alignment, and cross-section shown on the drawings. Care shall be taken to secure a uniform grade on the ditches so that the water will readily drain out, and to secure smooth, uniform slopes on the ditch banks in strict conformance with the drawings.

15. **Clearing and Grubbing.**—The ground included in the highway must be cleared of trees, stumps, brush, weeds and grass to the full width of right-of-way, unless otherwise directed. All timber, stumps, brush, and other vegetable matter must be burned unless otherwise directed by the engineer. Such material shall not be placed in the embankments.

Where embankments are to be more than two and one-half feet in height, it will be sufficient to cut all trees, stumps, and brush close to the ground. Where embankments are to be less than two and one-half feet in height, and in all excavations, all stumps and large roots must be grubbed out and burned or removed.

Unless otherwise specified, clearing and grubbing will be paid for as extra work, as provided in Section Two, paragraph 22. Allowance will be made for all grubbing in excavations for the roadbed, all grubbing in borrow pits ordered and staked out by the engineer to supply material for the embankments, and all grubbing in embankments less than two and one-half feet high, but will not be allowed for embankments over two and one-half feet high, or in borrow pits made by the contractor without having been so ordered by the engineer.

16. **Hedge rows.**—Hedges, under these specifications, are rows of trees or bushes, used for fence purposes or wind breaks, containing at least three bushes or trees per rod. For removing such hedges the contractor will be paid the price bid per rod.

17. **Measurements.**—Grading shall be estimated and paid for by the cubic yard at the prices specified in the tender. Measurements of grading quantities will, in all cases, be made from the cuts or pits from which the material is taken, by cross-sectioning before and after excavation, and the volumes determined by the average end area method.

18. **Haul and Overhaul.**—The average length of haul shall be determined by locating the center of gravity of the cut and the center of gravity of the corresponding fill. If the center of gravity of the cut is more than five hundred (500) feet from the center of gravity of the corresponding fill, overhaul at the rate of one cent per cubic yard per 100 feet will be allowed for the entire amount of material in the cut for the distance between the centers of gravity in excess of five hundred (500) feet.

Note.—Should the engineer desire to eliminate any payment for overhaul, a stipulation to that effect may be inserted in the instructions to bidders, as provided in Section Two, paragraph 25.

19. **Tile Sub-drains.**—Tile sub-drains shall be put in wherever shown on the plans. The tile used shall meet the requirements of the standard specifications for farm drain tile adopted in 1916 by the American Society for Testing Materials. The tile shall be laid true to grade and alignment established by the engineer. For furnishing and laying tile drains, the contractor will be paid at the price bid for such work.

Note.—The first requirement of road construction is to get a well-drained roadbed. For this reason, county engineers are instructed to require tile drainage on all portions of the highways where there is any question regarding the adequacy of the surface drainage or the stability of the soil.

If possible, the flow line of the tile shall be placed a minimum depth of five feet below the elevation of the roadway shoulders. No tile less than six inches in diameter shall be specified.

Where the grade of the side ditch is less than one per cent., inlets to the tile shall be provided at intervals of about five hundred feet. These inlets shall be constructed by filling the trench for a length of about three feet with coarse gravel, broken stone, or other suitable proous material. The top of the porous material shall be raised about eight inches above the top of the trench.

20. **Finishing Stakes.**—The engineer shall set suitable finishing stakes to guide the contractor in finishing the road.

Note.—One of the most common defects in earth road construction is the failure to bring the earth shoulders up to the proper grade and alignment. The shoulders are often left low and irregular, thus resulting in an unsightly road having too much crown in the center. This defect can be obviated only by setting stakes, giving the grade and alignment of the shoulders. In finishing, the contractor should use a templet to fit the crown of the road, and in this case stakes need be set only along one shoulder or along the center line. If no templet is used, finishing stakes should be set along each shoulder and on the center line.

Finishing stakes on fills should be set above the established grade so as to

allow the proper amount of shrinkage. Under average conditions the following percentages for shrinkage should give satisfactory results:

Depth of Fill	Percentage of Shrinkage
Up to 5.0 feet	15%
5.0 feet to 12.0 feet	12%
12.0 feet to 18.0 feet	10%

21. **Finishing.**—If the road is not to be surfaced with gravel, the contractor shall, after having brought it substantially to grade, complete the work in such a manner that the finished road will be smooth and true to cross-section, grade and alignment. No extra compensation will be allowed for finishing as this work must be included in the price bid for excavation.

If the road is to be surfaced with gravel, the earthwork necessary for forming the sub-grade shall be executed in the manner specified for the class of gravel surfacing to be used. The preparation of the sub-grade for the gravel surfacing is not included in the price bid for earthwork.

22. **Installing Temporary Culverts.**—Temporary culverts will be construed to mean corrugated culverts, boiler pipe culverts, concrete tile culverts, or cast iron culverts not over thirty-six inches in diameter, and placed without permanent bulkheads. The county will furnish and deliver temporary culverts at the railroad station. The contractor will be required to haul, properly place, and fill over such culverts. For this he will be paid at the price bid per lineal foot.

Section Four

MATERIAL

1. **Gravel.**—The gravel used in the construction of Class A or Class B gravel roads shall be a pit or bank gravel conforming to the following specifications as to grading:

Passing a 2″ mesh screen	100%
Passing a 2″, retained on 1″ mesh screen	% to....... %
Passing a 1″, retained on ½″ mesh screen	% to....... %
Passing a ½″, retained on ⅛″ mesh screen	% to....... %
Passing a ⅛″ mesh screen	25% to....... %

The clay content shall not exceed fifteen per cent. (15%) by dry weight.

Engineer's Note.—The county engineer should make a careful sieve analysis of the gravel available for the work under consideration and should insert in the above blank spaces the percentages which will secure the best results, from the material at hand. A desirable road gravel should have a grading within the following limits:

Passing 2″ mesh screen	100%
Passing 2″ mesh, retained on 1″ mesh	20–40%
Passing 1″ mesh, retained on ½″ mesh	10–30%
Passing ½″ mesh, retained on ⅛″ mesh	15–35%
Passing ⅛″ mesh	25–40%

A gravel having over 60% passing a ⅛″ screen should not be used in gravel road construction, although such a material might be used in a sand-clay road.

2. **Clay Content.**—If the gravel used contains insufficient clay to bind it properly, additional clay shall be added in the manner specified for the class of road being constructed. If the gravel used contains too much clay, clean gravel or sand shall be added until the clay content is reduced to the proper percentage.

Note.—The county engineer shall carefully test the available gravel supply to determine the amount of clay binder, the percentage of oversized stones, and other information to enable the contractor to make intelligent bids on the work under consideration.

3. **Gravel Supply.**—The source of the gravel supply shall be stated in the instructions to bidders. Where the gravel is to be shipped in, the contractor will be required to furnish such material and pay all freight charges and costs

therefor. A price per cubic yard or per ton for such gravel on board cars at the station where it is to be unloaded shall be stipulated in the tender.

Where the gravel is to be secured from local deposits, such deposits shall be bought or optioned by the county. The right-of-way for a suitable road reaching such gravel deposits shall also be provided by the county.

4. **Stripping the Gravel Pits.**—Where the gravel pits are furnished by the county, the contractor shall do the necessary stripping, back-filling, and the necessary grading on the road leading to such pit. For this stripping, back-filling, and grading he will be paid at the price bid per cubic yard for earth excavation.

5. **Loading Gravel.**—The contractor shall use precautions in loading the gravel so as to secure the grading specified. The loading shall be done in such a way that the clay which is left on top of the gravel will be uniformly distributed throughout the material. Large lumps of clay or loam in the gravel will not be permitted. Oversized stones shall be removed during the loading.

NOTE.—If gravel is being secured from deposits that are quite variable, the county should station a man at the pit to see that a uniform mixture is secured in the loading, or should require the contractor to adopt a method of loading which will secure such uniformity.

6. **Right-of-way for Hauling Equipment.**—It is understood and agreed that in transporting the surfacing material, the contractor shall have the right to lay tracks on, or operate equipment over, any public highway, provided that the tracks shall be so laid as not to interfere with traffic; that the contractor is responsible for any accidents which may occur due to such railway having been laid on the highway, or to damages resulting from the highway being placed in an improper or dangerous condition, and that the public highway will be left in as good condition after the hauling is finished as when the same was started.

The contractor shall maintain at his own expense the road leading to the gravel pit and shall repair any damage to public roads because of his hauling over the same.

Motor trucks used in hauling shall not have a loading in excess of 400 pounds per inch width of tire. This loading shall include the weight of the truck as well as the material being transported.

7. **Crushing Oversized Stone.**—The contractor under these specifications shall not be required to crush any oversized stones unless a clause to that effect is inserted in the instructions to bidders. If such a requirement is made, the contractor shall furnish all equipment, material, and labor necessary to crush such stone, so that it will meet the requirements of Section Four, Paragraph No. 1, with reference to size. Suitable means shall be provided for mixing this crushed material with the other gravel so that a uniform product is secured.

Where crushing of oversized stone is required, a price per cubic yard for such crushing shall be received.

Section Five

CLASS A GRAVEL SURFACING

1. **Class A Gravel Surfacing.**—Class A gravel surfacing shall consist of two courses of gravel of the thickness and width shown on the plans. The sub-grade and each course of gravel shall be compacted by rolling. (See Plate No. 34, page 140.)

2. **Earthwork.**—Before any gravel surfacing is laid, the earth road shall have been brought to grade and cross-section, and the sub-grade prepared in in the manner specified.

3. **Preparation of Sub-grade and Shoulders.**—The sub-grade for the lower course shall be shaped by excavating to the width shown on the cross-section for the lower course, and to a depth such that the top surface of the lower course will conform to the grade and cross-section shown on the plans. The material excavated shall be used for constructing the shoulders for the upper course. The edge of the trench shall be true to alignment and shall be as nearly vertical as the nature of the soil will permit. Before the upper course of gravel is placed, the earth shoulders for that course must be brought to the proper alignment and to such height that they will compact under rolling to the proper thickness for this course.

4. **Lateral Drains.**—In clay soils, lateral drains shall be constructed at intervals of from 50 ft. to 100 ft. as may be directed by the engineer. These drains shall be about 12″ wide and shall be cut to such depth that they will drain freely from the sub-grade of the lower course to the side ditch. About 5″ of coarse gravel shall be placed in the trench and shall be covered with earth to the level of the shoulder. On hills over four per cent. (4 %) grade, the lateral drains shall slope down hill at an angle of seventy degrees with the center line and shall be cut through to the center of the road.

5. **Rolling the Sub-grade.**—After the sub-grade for the lower course has been properly shaped, it shall be rolled until thoroughly compacted and the roller leaves no perceptible track thereon. If, during the rolling, soft places appear, this material shall be removed and replaced with new material which can be properly compacted under the roller. If sandy places are encountered, sufficient clay shall be added to permit proper rolling.

6. **Placing the Lower Course.**—The gravel for the lower course shall be placed on the sub-grade and spread uniformly to a depth such that when rolled it will have the thickness shown on the plans for this course. Ruts or depressions in the sub-grade caused by hauling over the same must be kept filled so as to present a smooth, uniform surface for receiving the gravel. After being evenly spread, the lower course of gravel shall be harrowed three times, or more if necessary, to secure a uniform distribution of the fine and coarse particles. Any oversized stones which are brought to the surface by the harrowing shall be raked out and placed on the sub-grade, or in the lateral drains, or removed from the road entirely.

7. **Rolling the Lower Course.**—After the lower course has been harrowed it shall be rolled until thoroughly compacted, and the roller leaves no perceptible track thereon. The additional sub-grade for the second course shall be shaped before the rolling for the lower course begins. The rolling for the lower course shall begin on the additional sub-grade for the upper course and the roller shall be worked gradually towards the middle of the road, after which it shall be taken to the opposite side and the other half of the road rolled in the same manner.

To aid in the compaction of the gravel, the rolling must be done when the material has been wetted sufficiently by sprinkling or by rain to secure the maximum compaction possible with the gravel being used. All hollows that develop during rolling shall be filled with the same grade of gravel and rerolled.

8. **Placing the Upper Course.**—The upper course of gravel shall be spread and harrowed in the manner specified for the lower course. Ruts caused by hauling over the gravel must be kept filled by frequent use of the grader, drag, or planer. If it appears that the gravel contains insufficient clay to bond properly, clay in the proper quantities shall be added to the lower course prior to placing the upper course.

9. **Rolling the Upper Course.**—After the upper course has been placed, the earth shoulders therefor shall be built up to such a height that when compacted by rolling they will be true to cross-section and elevation. The upper course of gravel shall be heavily sprinkled and then rolled until thoroughly compacted and the roller makes no appreciable track therein. If a gravel deficient in binding material has been used, rolling shall continue until the clay which was previously spread on the lower course is forced up through the upper course and the gravel is well bonded. If excess clay should appear in the surface, sand shall be spread over the surface as directed by the engineer and the rolling continue until there is no apparent excess clay. Depressions which may appear during the rolling of the upper course of gravel shall be removed by smoothing the surface with the blade grader or planer or by adding additional gravel of the same quality as that used in the upper course.

In rolling the upper course the roller shall start at least two feet out on the earth shoulder and shall be gradually worked towards the crown of the road, after which it shall be taken to the opposite side and the other half of the road completed in the same manner.

10. **Material.**—See Section Four.

11. **Cleaning Side Ditches and Shaping Earth Shoulders.**—After the rolling of the upper course is completed, the earth shoulders shall be neatly finished true to cross-section, grade and alignment, the side ditches shall be cleaned true to grade and cross-section, and, if necessary, the outlets shall be improved to allow free discharge of surface water.

12. **Machinery.**—(a) Roller. The roller used on this work shall be a self-propelled, three-wheeled roller, weighing not less than eight nor more than twelve tons. (b) A spiked tooth harrow weighing not less than eight pounds per tooth and having teeth of sufficient length to reach to the full depth of each layer of gravel, shall be used. (c) Sprinkler. The sprinkling tank shall be equipped with a suitable spray designed to sprinkle a strip of at least six (6) feet wide.

13. **Items Included in Prices Bid.**—See Section Seven.

Section Six

CLASS B GRAVEL SURFACING

1. **Class B Gravel Surfacing.**—Class B gravel surfacings shall consist of a single course of gravel of the thickness and width shown on the plans. Unless otherwise specified in the instructions to bidders, Class B gravel surfaces shall be constructed without rolling. (See Plate No. 34, page 140.)

2. **Earthwork.**—Before any gravel surfacing is laid, the earth road shall have been brought to grade and cross-section, and the sub-grade prepared in the manner herein specified.

3. **Preparation of Sub-grade.**—Along the center line of the finished earth roadway the crown on the road for the proper width shall be shaped to conform with the sub-grade shown on the gravel cross-section. The finished sub-grade shall present a smooth, uniform surface, parallel to the grade line shown on the plans. It shall be excavated to such a depth, or the earth shoulders shall be raised to such a height that the crown of the finished road shall conform from shoulder to shoulder to the crown shown on the standard cross-section.

4. **Lateral Drains.**—Where necessary, lateral drains shall be cut through the shoulders of the earth roadway, into the side ditches. These drains shall be constructed as specified in Section Five, paragraph 4. These drains shall be placed at low places in the grade and at such additional points as may be directed by the engineer.

5. **Placing the Gravel.**—After the sub-grade is prepared, sufficient gravel shall be placed thereon to give the required thickness when compacted.

NOTE.—By placing the loose gravel 6″ thick at the middle and 5″ thick at each edge, the compacted gravel surfacing should conform substantially to the standard cross-section for Class B road.

6. **Earth Shoulders.**—Suitable earth shoulders shall be constructed to prevent the gravel from spreading beyond the width shown on the cross-section. These shoulders may be constructed by excavating a trench in the earth roadway and using the material thus excavated to finish the earth shoulders, or the shoulders may be constructed by bringing up additional earth from the sides of the road.

7. **Spreading and Harrowing the Gravel.**—The gravel may be spread with shovels after being placed, or a quantity may be placed and spread with a road machine. After the material has been spread to a uniform thickness it shall be harrowed not less than three times with a spiked tooth harrow weighing not less than eight pounds per tooth, and having teeth of sufficient length to stir the material to its entire depth. All over sized pebbles which appear during the harrowing shall be carried ahead and placed on the sub-grade or in the lateral drains, or shall be removed from the road entirely.

8. **Material.**—See Section Four.

9. **Adding Clay Binder.**—By order of the engineer, additional binder in the quantities designated shall be spread uniformly over the surface of the gravel. The clay and gravel shall then be thoroughly mixed by harrowing, discing, or other suitable means. The mixing shall be done only after the road has been wetted either by sprinkling or by rain. Care shall be taken in adding the binder, as sod, foreign material, or material deficient in binding properties will not be permitted on the gravel road.

10. **Cleaning Side Ditches and Shaping Earth Shoulders.**—After the gravel surfacing is completed, the earth shoulders shall be neatly finished true to cross-section, grade and alignment, the side ditches shall be cleaned true to grade and cross-section, and, if necessary, the outlets shall be improved to allow free discharge of surface water.

11. **Rolling.**—If rolling is specified in the instructions to bidders, the sub-grade and gravel surface shall be rolled as specified in Section Five for Class A gravel surfaces.

12. **Items Included in Price Bids.**—See Section Seven.

42.5. The quantity to be paid for under this item shall be the number of cubic yards of compacted material in the completed course. The amount to be estimated shall be computed by multiplying the finished cross-section of the foundation course as shown upon the plans or ordered by the Engineer, by the length of the foundation course measured along the axis of the pavement. The price bid shall include the furnishing, placing, filling, rolling of the material and all labor and incidental expenses necessary to complete the work.

BOTTOM COURSE

Item 43—"Run of Bank" Gravel

43.1. Under this item the Contractor shall furnish and place approved "Run of Bank" gravel either upon the properly prepared sub-grade or upon the foundation course. The work shall be performed in full conformity to the specifications given under sections 44.2 to 44.9 inclusive, so far as same are not inconsistent with the use of such gravel.

43.2. All gravel shall be of hard, durable stone satisfactory to the Engineer. The particles shall be of such size as will pass through a 3½-inch circular hole, and shall be well graded. Gravel shall be of such nature that the material passing a ¼-inch screen shall not be more than 5 per[1] centum in excess of the voids in the remaining material after its separation therefrom. Before using "Run of Bank" gravel in the work the same shall be tested to determine its suitability. Should at any time during the work and for any reason the gravel fail to maintain suitable proportions of the coarse and fine particles, the Contractor shall by the addition of selected material and satisfactory manipulation produce a material meeting the above requirements.

43.3. The depth of loose stone or gravel in all cases, whether in foundation, bottom or top courses, shall be gauged by the use of cubical blocks of suitable size. (See page 591.)

43.4. The spreading of any layer or course of broken stone, gravel or filler, whether in foundation, bottom or top courses, shall be done from suitable spreader wagons or from piles dumped along the road as directed by the Engineer.

No segregation of large or fine particles will be allowed, but the stone as spread shall be well graded with no pockets of fine material.

43.5. The quantity to be paid for under this item shall be the number of cubic yards of compacted material in place in the completed course. The amount to be estimated shall be computed by multiplying the finished cross-section of the bottom course as shown on the plans or ordered by the Engineer, by the length of the bottom course measured along the axis of the pavement.

The price bid shall include the furnishing, placing, rolling and filling the material, and all other labor, materials and incidental expenses necessary to satisfactorily complete the work.

Item 44—Bottom Course—Screened Gravel

Item 45—Bottom Course—Broken Stone

44.1. Under these items the Contractor shall furnish and place stone or gravel, conforming to the general requirements for same, either upon the properly prepared sub-grade or upon the foundation course. This stone or gravel shall be of sizes specified below.

44.2. After the sub-grade or foundation course shall have been properly prepared and proper drainage provided, a course of broken stone or gravel of graded No. 3 or No. 4 or a uniform mixture of same shall be spread evenly so that it will have after rolling the required thickness. If specifically allowed by the Engineer a limited amount of No. 2 stone may be used in the bottom course. (For the meaning of these numbers in connection with size see page 720).

In cases where the finished thickness of the bottom course is to be more than 5 inches, the broken stone or gravel for it shall be spread, rolled and filled in two separate layers neither of which shall be of a greater depth than 6 inches measured loose.

[1] Not feasible, see page 156.

44.3. The depth of loose stone or gravel in all cases, whether in foundation, bottom or top courses, shall be gauged by the use of cubical blocks of suitable size. (See page 591.)

44.4. The spreading of any layer or course of broken stone, gravel or filler, whether in foundation, bottom or top courses, shall be done from suitable spreader wagons or from piles dumped along the road as directed by the Engineer.

No segregation of large or fine particles will be allowed, but the stone spread shall be well graded with no pockets of fine material.

44.5. After the bottom course of stone or gravel has been laid loose it shall be thoroughly rolled with an approved roller weighing not less than ten tons.

This rolling must begin at the sides and continue toward the center and shall continue until there is no disturbance of the stone ahead of the roller. After the stone is thoroughly compacted No. 1 stone or gravel, and screenings or sand, or a mixture of these, shall be uniformly spread upon the surface and swept in with rattan or steel brooms and rolled dry. After the completion of the rolling no teaming other than that necessary for bringing material for the next course shall be allowed over the rolled material. It is the intention to bind this course with the small stone, but not to use so much that a good bond will not be secured between the bottom and top courses.

44.6. When two courses of bottom stone are laid each course shall be treated by rolling and adding fine material as described above.

44.7. If the sub-grade material shall become churned up into or mixed with the bottom or sub-bottom courses through the Contractor's hauling over it or working on it when the sub-grade is in a wet condition, the Contractor shall at his own expense remove such mixture of sub-grade material and broken stone and replace it with clean broken stone of the proper size, and shall roll or otherwise compact the material so as to produce a uniform, firm and even bottom course.

If the above condition occurs through no fault of the Contractor, the Contractor shall be paid both for excavating and replacing under the items "Excavation" and "Bottom Course" respectively.

44.8. All filler for top and bottom courses shall be delivered and piled alongside the road before the course in which it is to be used is placed.

44.9. The quantity to be paid for under these items respectively shall be the number of cubic yards of compacted material in place in the completed course. The amount to be estimated shall be computed by multiplying the finished cross-section of bottom course as shown upon the plans or ordered by the Engineer, by the length of the bottom course measured along the axis of the pavement.

The price bid for the respective items shall include the furnishing, placing, filling, rolling of the material and all labor and incidental expenses necessary to complete the work.

Item 46—Concrete Foundation for Pavement

46.1. Under this item the Contractor shall furnish and place upon a propery prepared sub-grade, concrete foundation for pavement of the thickness shown upon the plans or ordered by the Engineer.

46.2. Concrete foundation shall not be placed on any sub-grade until the sub-grade has been properly drained, thoroughly rolled and compacted, and is true to line and grade in horizontal and transverse cross-section.

46.3. Concrete shall consist of a mixture of Portland cement, No. 2 or No. 3 sand and broken stone or gravel. The coarse aggregate shall consist of a well-mixed product of No. 2 and No. 3 stone or No. 2 and No. 3 gravel. The fine aggregate shall consist of No. 2 or No. 3 sand. All of these materials shall conform in all respects to the requirements given under "Materials of Construction," pages 717 to 720. All specifications relating to second-class concrete shall apply to work done under this item, in so far as they are not inconsistent with the special specifications given below.

46.4. The concrete shall be mixed in the proportions of one volume of cement to two and one-half volumes of sand and five volumes of broken stone or gravel. The relative proportions of fine and coarse aggregate may be varied slightly, as a result of tests for voids by the Engineer, to

a distance greater than one (1) mile. The method of determining overhaul will be in all respects similar to that provided for determining overhaul in the case of crushed stone surfaces.

GRAVEL SURFACE (ALABAMA STATE SPECIFICATIONS)

Description.—On the sub-grade, prepared as hereinbefore specified, shall be constructed a gravel surface of the cross-section and compacted thickness shown on the plans.

Gravel.—Before any gravel is used in the construction of the road surface, it shall first have been approved by the Engineer. All gravel pits will be furnished by the County, and in general, those which are acceptable will be indicated in the special provisions accompanying the proposal form. The contractor, however, must provide and maintain roads to such pits at his own expense.

When gravel for the surface is to be shipped in, it will, unless otherwise specified in the special provisions, be furnished by the County, f. o. b. cars at such sidings as the engineer and contractor may agree upon. The contractor shall unload cars promptly, even though the gravel has to be dumped on the ground and re-handled. Gravel will be furnished as it is needed by the contractor, in so far as the County can secure the desired service from the railroads, but the County will not be responsible for any damage which the contractor may sustain on account of delays or irregularities on the part of railroads in furnishing cars or in delivering the gravel at the sidings. The contractor shall be responsible for any and all demurrage charges made by the railroads on account of delays in unloading cars. When the County has to pay demurrage charges resulting from failure on the part of the contractor to unload the cars promptly, the amounts so paid will be charged to the contractor and deducted from amounts that may be or become due the contractor for work performed or materials delivered.

If it is deemed advisable to add screened gravel or clay to the gravel before it is used as surfacing material, it will be so specified in the special clauses accompanying the proposal form. The screened gravel or clay will be selected by the engineer and furnished by the County, either in pits or at railroad sidings, according to the conditions specified in the preceding paragraph. The work of admixing the screened gravel or clay with the gravel, shall be done by the contractor and as hereinafter specified under construction methods.

Construction Methods.—The gravel shall be spread on the sub-grade to such depth that when compacted the surface will have the compacted thickness shown on the plans. It shall be dumped and spread in the manner hereinbefore specified for dumping and spreading No. 1 and No. 2 crushed stone, in the case of crushed stone surfaces. If rolling is to be required it will be so specified in the special clauses accompanying the proposal form and shall be done in the manner hereinbefore specined for rolling crushed stone surfaces.

When the specifications call for admixing clay with the gravel, this shall be done in strict accordance with the following directions:

1. The proportion in which the clay shall be added is to be determined by the engineer, and the engineer may change the proportion from time to time, as the exigencies of the case may warrant.

2. If practicable, the loading of the clay and gravel shall be so managed that each load hauled to the road will contain the proper proportion of each, so mixed in loading that in dumping and spreading each material will be uniformly distributed. If it is impracticable to load the two materials at the same time, they may be hauled to the road separately, in which case, the engineer will determine the order in which the clay shall be spread and the depth of layer required.

3. Wherever clay is to be mixed with the gravel, as above provided, and no matter whether the gravel and clay are hauled together or separately, as soon as the materials for four or five hundred (400 or 500) linear feet of surface have been spread, the entire mass shall be thoroughly mixed by means of plowing and harrowing, and the plowing and harrowing shall continue until the entire surface is free from lumps or pockets of clay and the engineer is satisfied that the two materials are uniformly distributed throughout the mass. As soon as the mixing is completed to the engineer's satisfaction, the surface shall be shaped to conform with the plans, and rolled, if rolling is specified.

When screened gravel is to be added to the surfacing gravel, the method of mixing the two materials shall be similar in all respects to that specified for admixing clay with surfacing gravel.

Basis of Payment.—The contract price per cubic yard for gravel for surfacing shall be full compensation for loosening, loading, spreading, rolling (if rolling is specified), hauling the gravel one (1) mile or less, and maintaining the surface true to cross-section until the road is accepted. Measurement of gravel will be made in trucks, wagons or cars as the gravel is delivered. Stripping of gravel pits will be paid for at the contract price for common excavation. The bid price for overhaul of gravel will be paid on gravel necessarily hauled a distance greater than one (1) mile. The method of determining overhaul will be in all respects similar to that provided for determining overhaul in the case of crushed stone surfaces.

Where the specifications call for clay or screened gravel to be admixed with the surfacing gravel, these will be paid for at the contract rates for surfacing gravel and according to the schedule outlined in the preceding paragraph. The contract price for admixing clay or screened gravel will be full compensation for all plowing, harrowing, etc., that may be necessary in securing a thorough mixture of the two materials.

TOP SOIL OR SAND-CLAY SURFACE (ALABAMA STATE SPECIFICATIONS)

Description.—Upon the sub-grade, prepared as hereinbefore specified shall be constructed a top soil or sand-clay surface of the cross-section and compacted thickness shown on the plans.

Surfacing Material.—The surfacing material shall consist of top soil or natural sand-clay obtained from fields or pits designated by the engineer, and as near the right-of-way as practicable, or, in the event that it is impracticable to secure suitable top soil or natural mixed sand-clay, the surface shall consist of an artificial mixture of sand and clay, the materials for which artificial mixture shall be obtained from places designated by the engineer. Before any surfacing material is used it shall first have been approved by the engineer. The surfacing material shall be free from trash or other foreign matter and contain no stones or boulders that would fail to pass a one and one-half (1½) inch ring. Should any such non-road building material be placed on the road, it shall be removed by the contractor at his own expense.

The fields or pits from which the surfacing material is to be obtained will be furnished by the County free of charge to the contractor, but the contractor must provide and maintain at his own expense, all necessary roads for hauling the surfacing material to the road.

Construction Methods—Case 1.—Where the surfacing material consists of either top soil or natural sand-clay that has been approved for use without the admixture of any other material, it shall be evenly spread on the sub-grade to such depth that when compacted the surface will have the compacted thickness shown on the plans. The material shall be dumped on the sub-grade in longitudinal rows containing not more than one-third (⅓) of a cubic yard to 10 lineal feet, and the number of rows shall be such that when the material is spread, the desired cross-section and thickness of surface will be obtained. After sufficient material has been dumped in this way for one hundred or two hundred (100 or 200) feet of road surface, and before any part of the rows have commenced to pack, it shall be spread approximately to the required cross-section and harrowed to secure uniformity. The spreading may be done by hand or with a road machine in the following manner: 1. The machine shall be run over the road with the blade set so as to scrape off the tops of the piles and fill in the spaces between; 2. The outside edges shall be gone over with the blade set so as to pull the top soil or sand-clay toward the center; 3. The grading machine shall be run over the shoulders so as to pull the shoulder material up against the surfacing material and thus bring the entire road surface approximately to the required cross-section. The surfaced portion of the road shall then be harrowed with either a tooth or disc harrow until uniform density is secured, after which the road shall be brought to the required cross-section and so maintained until accepted. The shaping or reshaping of the surface shall be undertaken only when the weather conditions are such that the loosened surfacing or shoulder material will be readily compacted by traffic to form a well bonded surface.

Case 2.—When the surfacing material is to consist of an artificial mixture of sand and clay, made by mixing the material of the roadbed with sand or clay from some other source, the construction shall proceed in the following manner:

1. The surface of the roadbed shall be thoroughly loosened by plowing and harrowing to a depth of from 4 to 8 inches, according to the nature of the two materials to be mixed, and as the engineer may direct.

2. The material to be added shall be dumped and spread in the manner described for Case 1.

3. The added material shall be thoroughly mixed and incorporated with the material of the road-bed. The mixing shall be done by means of plowing and harrowing and shall continue until the engineer is satisfied that the two materials are thoroughly mixed in proper proportion. A part of this mixing shall be done when the road is wet so that the surface will be puddled.

4. If, after mixing the two materials as above described, a deficiency of the added material is apparent at any point, such deficiency shall be immediately corrected by spreading more of the added material at that point and continuing the mixing as above described.

5. After the mixing is complete, as above specified, the road shall be shaped and maintained as provided in Case 1, except that wherever a poor mixture is observed, it shall be corrected by additional mixing or by adding necessary material and mixing.

Case 3.—When the surfacing material is to consist of an artificial mixture of sand and clay, both of which materials are to be obtained from without the road, the construction shall proceed in the following manner:

1. The materials shall be spread in successive layers on the road and mixed in place. The engineer will determine the order in which the two materials shall be spread, as well as the depth of layer for each material.

2. The dumping and spreading of the materials shall be done as specified for Case 1.

3. The mixing of the two materials and the shaping and maintaining of the road shall be done as specified for Case 2.

Basis of Payment.—The contract price per cubic yard for top soil or natural sand-clay surfacing material shall be full compensation for loosening, loading, spreading and harrowing, and for hauling the surfacing material one (1) mile or less, as well as for shaping and maintaining the surface true to cross-section until the road is accepted. In the case of an artificially mixed surface the materials brought on to the road will be paid for at the contract price per cubic yard for top soil or natural sand-clay surfacing material, which will include all the items mentioned above except harrowing, and the contract price per square yard for mixing will be full compensation for all necessary harrowing, plowing or other mixing. Measurement of all top soil or sand-clay surfacing materials will be made in trucks, wagons or cars, as it is delivered on the road, except that where the surfacing material is hauled in scrapers or shoveled on to the road, it will be measured compacted in place on the road.

Stripping of surfacing material pits will be paid for at the contract price for common excavation.

The bid price for overhaul of sand-clay will be allowed on all sand-clay materials necessarily hauled a distance greater than one (1) mile. The method of determining overhaul will be in all respects similar to that provided for determining overhaul in the case of crushed stone surfaces.

TOP COURSE (NEW YORK STATE SPECIFICATIONS, ITEMS 47 to 55)

Item 47—Top Course—Water Bound Macadam—Gravel

47.1. Under this item the Contractor shall furnish and place upon the bottom course, gravel of an approved character to form the top course.

47.2. The top course shall consist of approved gravel of the character hereinbefore specified and of the thickness shown on the plans, together with the binder necessary to properly fill and bind the course. For this purpose gravel of No. 3 size with, when approved by the Engineer, a certain amount of No. 2 size, may be used. (See page 720 for meaning of these numbers as to size.) Run of bank gravel shall not be used except by written permission of the Division Engineer; this permit must be given in advance, shall specify the locality from which it is to be taken, and contain a proviso that if the material should at any time become unsatisfactory its use shall at once

When screened gravel is to be added to the surfacing gravel, the method mixing the two materials shall be similar in all respects to that specified r admixing clay with surfacing gravel.

Basis of Payment.—The contract price per cubic yard for gravel for surcing shall be full compensation for loosening, loading, spreading, rolling : rolling is specified), hauling the gravel one (1) mile or less, and mainining the surface true to cross-section until the road is accepted. Measement of gravel will be made in trucks, wagons or cars as the gravel is livered. Stripping of gravel pits will be paid for at the contract price for mmon excavation. The bid price for overhaul of gravel will be paid on avel necessarily hauled a distance greater than one (1) mile. The method : determining overhaul will be in all respects similar to that provided for etermining overhaul in the case of crushed stone surfaces.

Where the specifications call for clay or screened gravel to be admixed ith the surfacing gravel, these will be paid for at the contract rates for ırfacing gravel and according to the schedule outlined in the preceding aragraph. The contract price for admixing clay or screened gravel will e full compensation for all plowing, harrowing, etc., that may be necessary n securing a thorough mixture of the two materials.

TOP SOIL OR SAND-CLAY SURFACE (ALABAMA STATE SPECIFICATIONS)

Description.—Upon the sub-grade, prepared as hereinbefore specified shall be constructed a top soil or sand-clay surface of the cross-section and compacted thickness shown on the plans.

Surfacing Material.—The surfacing material shall consist of top soil or natural sand-clay obtained from fields or pits designated by the engineer, and as near the right-of-way as practicable, or, in the event that it is impracticable to secure suitable top soil or natural mixed sand-clay, the surface shall consist of an artificial mixture of sand and clay, the materials for which artificial mixture shall be obtained from places designated by the engineer. Before any surfacing material is used it shall first have been approved by the engineer. The surfacing material shall be free from trash or other foreign matter and contain no stones or boulders that would fail to pass a one and one-half (1½) inch ring. Should any such non-road building material be placed on the road, it shall be removed by the contractor at his own expense.

The fields or pits from which the surfacing material is to be obtained will be furnished by the County free of charge to the contractor, but the contractor must provide and maintain at his own expense, all necessary roads for hauling the surfacing material to the road.

Construction Methods—Case 1.—Where the surfacing material consists of either top soil or natural sand-clay that has been approved for use without the admixture of any other material, it shall be evenly spread on the subgrade to such depth that when compacted the surface will have the compacted thickness shown on the plans. The material shall be dumped on the sub-grade in longitudinal rows containing not more than one-third (⅓) of a cubic yard to 10 lineal feet, and the number of rows shall be such that when the material is spread, the desired cross-section and thickness of surface will be obtained. After sufficient material has been dumped in this way for one hundred or two hundred (100 or 200) feet of road surface, and before any part of the rows have commenced to pack, it shall be spread approximately to the required cross-section and harrowed to secure uniformity. The spreading may be done by hand or with a road machine in the following manner: 1. The machine shall be run over the road with the blade set so as to scrape off the tops of the piles and fill in the spaces between; 2. The outside edges shall be gone over with the blade set so as to pull the top soil or sand-clay toward the center; 3. The grading machine shall be run over the shoulders so as to pull the shoulder material up against the surfacing material and thus bring the entire road surface approximately to the required cross-section. The surfaced portion of the road shall then be harrowed with either a tooth or disc harrow until uniform density is secured, after which the road shall be brought to the required cross-section and so maintained until accepted. The shaping or reshaping of the surface shall be undertaken only when the weather conditions are such that the loosened surfacing or shoulder material will be readily compacted by traffic to form a well bonded surface.

previously placed alongside the pavement, and immediately swept in and thoroughly rolled. Care must be taken throughout to add the binder only in light coatings and to thoroughly sweep each coating in order that the maximum amount of binder may be worked in to fill the voids. The spreading and sweeping and rolling shall be continued until no more binder will go in dry, after which the macadam shall be sprinkled until saturated, the sprinkler being followed by the roller. If the sub-grade should become wet to such an extent that the pavement becomes unstable and waves under the roller, the roller shall be taken off and this portion left to dry out before puddling is resumed.

More screenings shall be added where necessary, and the sweeping, sprinkling, and rolling shall continue until a grout has been formed that shall fill all the voids and be pushed into a wave by the wheels of the roller. After the wave of grout has been produced over the whole section of the macadam this portion shall be left to dry out, after which it shall be opened to traffic. The macadam shall be repuddled and back-rolled on succeeding days as much as may be necessary to secure satisfactory results. The macadam shall then be covered with a wearing carpet of screenings at least three-eighths of an inch thick; this wearing carpet shall be maintained and renewed until the whole road is accepted. During all the working hours when the roller is not needed for rolling the fills, sub-grade, shoulders and unfinished courses of the pavement, it shall be employed in back-rolling the earlier portions of the macadam.

48.4. The quantity to be paid for under this time shall be the number of cubic yards of compacted material in place in the completed course. The amount to be estimated shall be computed by multiplying the finished cross-section of the top course as shown on the plans or ordered by the Engineer, by the length of the top course measured along the axis of the pavement.

The price bid shall include the furnishing, placing, rolling, filling and puddling of the material, and all labor, material and incidental expenses, necessary to complete the work.

No. 1 stone or gravel, chips or screenings remaining loose on the surface after the work is completed shall not be estimated as a part of the depth of the top course, but payment therefor shall be included in the price bid for this item.

Item 49—Cleaning Old Pavement

49.1. The purpose of the work called for under this item is to prepare an old macadam or old concrete surface for the application of a new top course or a wearing carpet.

49.2. Under this item the Contractor shall clean the old macadam or concrete surface by the use of seal hand brooms or by the use of mechanical sweepers of approved type, as directed by the Engineer, so as to completely uncover but not dislodge the embedded stones of the pavement.

All mud, dust, and other dirt so swept off shall then be removed and deposited in such places and in such manner as the Engineer may direct.

49.3. Ruts and depressions of a greater depth than one inch below the general surface of the pavement shall be completely swept out by hand brooms until all loose material has been removed and the embedded stones are fully uncovered.

This operation of cleaning out the ruts and depressions and filling them with thoroughly compacted stone and binder to the general level of the surface, shall precede the general operation of cleaning the macadam surface.

49.4. The amount to be paid for under this item shall be the actual number of square yards of old macadam or concrete, including ruts and depressions, cleaned in accordance with the above sections and to the satisfaction of the Engineer.

The price bid shall include all labor, tools, appliances, the removal of material cleaned from the surface, and all other expenses incidental thereto.

Item 50—Scarifying and Reshaping Old Macadam

50.1. The purpose of the work under this item is to prepare old macadam pavement for the application of a top course.

50.2. Under this item the Contractor shall thoroughly scarify the old macadam by hand picking or by means of a mechanical scarifier of approved type. Unless specifically authorized by the Engineer, the use of a roller with spiked wheels will not be permitted.

The loosened stones shall then be forked or raked over as directed by the Engineer, after which the macadam shall be compacted by rolling with a self-propelled roller weighing not less than 10 tons until an even and firm surface is produced. If necessary in order to satisfactorily compact the stones, the macadam shall be sprinkled during the process of rolling.

50.3. The quantity to be paid for under this item shall be the actual number of square yards, scarified, reshaped, rolled and compacted to the satisfaction of the Engineer, and the price stipulated shall include all labor appliances and expenses incidental thereto.

Item 51—Surface Treatments with Bituminous Material

51.1. Under this item the Contractor shall apply bituminous material and shall apply broken stone or gravel of specified sizes as a wearing carpet to a new or old pavement of macadam, concrete, or any other substance or type, as shown on the plans or ordered by the Engineer.

51.2. If the pavement to be treated is a newly built macadam or concrete' after it shall have become thoroughly dried and hardened, it shall be swept clean of all dust, dirt or other loose material; if ordered by the Engineer, the sweeping of the macadam shall be continued until the voids are exposed in the surface to a satisfactory depth, not exceeding one-half inch. The price bid, under this item, shall include the aforesaid cleaning of the pavements.

If the pavement to be treated is an old macadam or old concrete, the cleaning shall be paid for under item "Cleaning Old Pavement."

51.3. After the pavement shall have been cleaned to the satisfaction of the Engineer, and when dry, the bituminous material shall be uniformly sprayed over the surface by means of an approved pressure distributor. The bituminous material for hot application shall be heated to a temperature between 250 degrees and 350 degrees F. as required, and when tar is used, it shall be heated to a temperature between 200 degrees and 250 degrees F. as required.

The amount of bituminous material to be used in any one application shall not be less than one-sixth nor more than one-half gallon per square yard, the precise quantity depending upon the character of the pavement, the materials and the local conditions. The Contractor shall, therefore, be subject entirely to the direction of the Engineer in this respect.

51.4. The bituminous material applied as above specified shall then be immediately covered, while soft, with a uniform layer of approved broken stone of No. 2 or No. 1 size, after which the stone shall be rolled with a self-propelled roller of approved weight. If ordered by the Engineer another application of bituminous material shall then be made to be followed by an application of approved No. 2 stone or approved No. 1 stone, and again rolled to the satisfaction of the Engineer.

The quantity of No. 2 stone and of No. 1 stone to be used shall be sufficient to completely cover the bituminous material and shall be spread in two or more thin applications, the roller being used after each spreading. The total amount of stone to be used after each application of the bituminous material being that which will become imbedded under the pressure of the roller. The final application of the stone shall be of No. 1 size.

51.5. Gravel, which has been tested and approved for use, may be substituted for broken stone if screened to produce particles corresponding with No. 2 and No. 1 sizes.

51.6. No bituminous material for surface treatment shall be placed between October 15th and May 15th, except by written permission of the Engineer, nor when the air temperature on the work is below 50 degrees F., nor when the pavement is damp or in an otherwise unsatisfactory condition.

51.7. Under this item the Contractor shall be paid for the number of gallons of bituminous material furnished in and incorporated in the work in accordance with these specifications and the orders of the Engineer. Bituminous material, that has been wasted or that has been rendered unfit for use by over-heating or by long-continued heating, shall not be paid for. For purposes of measurement, a gallon shall be a volume of

231 cubic inches and measurement shall be based on the volume of the bituminous material at a temperature of 60 degrees F.

The price bid shall include the furnishing, hauling, heating and applying the bituminous material, and shall also include the spreading, rolling and incorporation of the stone into the wearing carpet.

This item shall not include the furnishing of the No. 1 and No. 2 stone or gravel, nor the delivery of same along the side of the road; these will be paid for under Items Screened Gravel or Broken Stone Loose Measure, respectively.

Item 52—Top Course Bituminous Macadam—Penetration Method

52.1. Under this item the Contractor shall furnish and lay a broken stone top course composed of fragments of the specified sizes, and incorporate therewith bituminous material introduced from the surface by means of an approved pressure distributor.[1]

[1] Hand spreading from pots or hods is more satisfactory for the first coat but not for the flush coat.

52.2. After the bottom course shall have been completed to the satisfaction of the Engineer, a course of approved No. 3 broken stone shall be evenly spread thereon in such quantity that after the application of the bituminous material and broken stone of smaller sizes, hereafter specified, the final compacted thickness of the top course shall be as called for on the plans or ordered by the Engineer.

The No. 3 stone shall then be smoothed out by passing over it a few times a self-propelled roller weighing approximately 10 tons, after which bituminous material of the kind specified in the proposal, heated to a temperature between 250 degrees and 350 degrees Fahrenheit if asphalt is used, and between 200 degrees and 250 degrees if tar is used, shall be evenly spreading over the surface. The quantity of bituminous material to be used in the first application shall be the amount ordered by the Engineer, which will approximate 1¾ gallons per square yard for a top course 3 inches thick, with a proportional reduction in the quantity for thinner courses.

The surface shall then be immediately covered with a layer of approved No. 2 broken stone, after which it shall be compacted with a self-propelled roller weighing approximately 10 tons; during the rolling process, additional No. 2 broken stone shall be applied and broomed about until the voids in the No. 3 stone are entirely filled.* The rolling shall be continued until the course of stone is thoroughly compacted and its surface is true and even to the established grade and conforms in all respects to the requirements specified for finishing and testing the surface of "Top Course Bituminous Macadam, Mixing Method—Type 1."

52.3. After this portion of the work shall have been completed to the satisfaction of the Engineer, all loose stone shall be swept from the surface and a sealing coat of one-half gallon of bituminous material per square yard shall be applied by means of an approved pressure distributor. After this it shall be immediately covered with approved No. 1 broken stone, spread and broomed about by experienced workmen, and again rolled; the rolling shall be continued and additional No. 1 stone shall be applied until a smooth, uniform surface is produced.

52.4. Before being opened to traffic a layer of No. 1 broken stone approximately one-half inch thick shall be spread loose on the surface for wearing course.

52.5. The quantity to be paid for under this item shall be the number of cubic yards of compacted material in place in the completed course. The amount to be estimated shall be computed by multiplying the finished cross-section of the top course, as shown upon the plans or ordered by the Engineer, by the length of the top course measured along the axis of the pavement.

The price bid shall include the heating and placing of the bituminous material, the furnishing, placing, rolling and filling of the broken stone, and all labor, materials, and incidental expenses necessary to complete the top course.

This item shall not include the furnishing and delivery of the bituminous

* Too much rolling is injurious while the oil is hot; better results are obtained by waiting till the next day to compact; the course should be rolled early in the morning for 10 days and gradually hardened down.

material; such furnishing and delivering will be paid for under the item covering such material.

No. 1 broken stone or gravel, chips or screenings remaining loose on the surface after the work is completed shall not be estimated as a part of the depth of the top course, but payment for these shall be included in the price bid for item 52.

Item 53—Top Course—Bituminous Macadam—Mixing Method. Type 1

53.1. Under this item the Contractor shall construct a top course of broken stone mixed with a bituminous material, upon a previously constructed bottom course of concrete, broken stone, quarry or field stone, or gravel. The surface laid shall be in conformity with the lines and grades shown upon the plans or ordered by the Engineer. A smooth finished surface will be insisted on free from irregularities and waviness. The entire top course shall consist of a wearing course finished over with a flush or sealing coat.

53.2. The broken stone used in this course shall be of approved material. When the top course is to be 2 inches or less in thickness in the completed work, the stone shall be of No. 2 size. When the top course is to be over 2 inches in thickness in the completed work, No. 2 and No. 3 stone shall be used, proportioned as directed by the Engineer. The sealing coat therefor shall be of stone of No. 1 size. (For stone sizes corresponding to these numbers, see page 720.)

53.3. Gravel of approved quality and corresponding to the same sizes as broken stone may be used in the top course. If used, it shall conform to the general requirements for broken stone and gravel for water-bound and bituminous macadam work.

53.4. The broken stone for the wearing course shall be heated, before entering the mixer, to between 225 degrees Fahrenheit and 300 degrees Fahrenheit in revolving dryers of an approved type. The stone shall be continuously agitated during the heating.

53.5. The bituminous material to be used in this course shall conform with the specifications for "Bituminous Material A for Mixing Method —Type I."

53.6. The bituminous material shall be heated in kettles so designed as to admit of even heating of the entire mass, with an efficient and positive control of the heat at all times. Bituminous material "A" shall be heated as directed to a temperature between 275 degrees Fahrenheit and 350 degrees Fahrenheit; all material heated beyond 350 degrees Fahrenheit, either before or during mixing with the broken stone, shall be rejected. Bituminous material "T" shall be heated as directed to a temperature between 200 degrees Fahrenheit and 275 degrees Fahrenheit; all bituminous material "T" heated beyond 275 degrees Fahrenheit either before or during mixing with the broken stone, shall be rejected. No tar shall be heated in kettles containing any asphalt cement, and no asphalt cement shall be heated in kettles containing any tar; before changing from one type of material to the other, kettles shall be scrupulously cleaned in order to avoid mixtures of the two; any such mixtures shall be rejected.

53.7. When thoroughly heated to the proper temperatures, the bituminous material and the broken stone for the wearing course shall be mixed as directed from time to time, using approximately 18 gallons of bituminous material per cubic yard of loose stone. (The amount of bitumen in the completed work shall be from 5 to 7½ per centum of the total weight of the completed course.) The Contractor shall provide approved means for accurately proportioning the mixture. Excess of bituminous material shall be prevented; and any such excess shall be cause for rejection of the course unless satisfactorily corrected previous to laying. The mixer used shall be of satisfactory design, having revolving blades and efficient means for keeping the temperature at the desired point without burning the liquid. The mixing shall continue until every particle of the broken stone is thoroughly coated with the bituminous material and a uniform mixture has been obtained, which when discharged shall have a temperature between 200 degrees and 300 degrees Fahrenheit for bituminous material "A" and between 200 degrees and 250 degrees Fahrenheit for bituminous material "T."

The use of batteries of small batch mixers will not be allowed.

53.8. The bituminous mixture, heated and prepared as specified above, shall be delivered from the mixer to the point of deposition in the pavement, if at a considerable distance, in suitable trucks or wagons, provided with canvas covers for retaining the heat. To prevent undue compacting on long hauls, partitions may be required for large truck loads. As delivered, the mixture shall have a temperature of at least 150 degrees Fahrenheit. Material having a lower temperature than this shall not be laid in the pavement. The mixture shall be immediately spread over the foundation course by men experienced in such work, so that when rolled it shall have the required thickness and shall be free from surface depressions and irregularities. The paving shall be done as continuously as practicable, to reduce to a minimum the number of joints between hot and cold materials. Such joints shall be constructed in an approved manner. The hot paving mixture shall not be dumped in large masses on the bottom course. It shall be dumped upon platforms and shoveled with hot shovels into position in the pavement.

53.9. The wearing course, placed as above specified, shall be rolled at once, while the material is still warm and pliable, beginning at the edges and working toward the center. Acceptable means shall be provided to prevent the asphalt from sticking to the roller. Rolling shall continue without interruption until all roller marks disappear and the surface shows no further compressibility. Places which the roller cannot effectively reach shall be compressed with hot iron tamps.

53.10. As soon as possible after the compacting of the wearing course, when the surface is clean and dry, a sealing coat of hot bituminous material "A" shall be evenly spread over the wearing course by means of approved pressure distributors. The bituminous material "A" shall be applied at a temperature not less than 275 degrees Fahrenheit nor more than 350 degrees Fahrenheit, at a rate of ½ to ¾ gallon per square yard, as directed. A thin and uniform layer of dry, clean No. 1 stone shall be immediately spread over the bituminous material "A" by machines or skilled workmen, sufficient to more than take up all the excess bituminous material "A." The spreading of the No. 1 stone shall not lag more than 20 feet behind the placing of the asphalt coating. The pavement shall then be again thoroughly rolled. The surface of the wearing course shall be kept scrupulously clean until the sealing coat is applied. The Contractor shall not permit any hauling over the surface before the completion of the sealing coat.

53.11. Before placing the sealing coat, the pavement shall be tested with a ten foot straight edge laid parallel with the center line of the pavement, and any depressions exceeding one-half inch shall be satisfactorily eliminated or the pavement relaid.

53.12. Rollers used for the bituminous wearing course and the sealing coat shall be well balanced, self-propelled rollers of satisfactory design, weighing between eight and ten tons. They shall give a compression under the rear roller of between 200 and 350 pounds per linear inch of roll, and shall be provided with an ash pan which shall prevent ashes from dropping upon the pavement.

53.13. No top course bituminous material shall be mixed or placed between October 15 and May 15 except by written permission of the Engineer, nor when the air temperature in the shade is below 50 degrees Fahrenheit, nor when the foundation is damp or otherwise unsatisfactory.

53.14. The Contractor shall provide a sufficient number of accurate efficient thermometers for determining the temperatures of the bituminous material and the broken stone at all stages of the work.

53.15. The quantity to be paid for under this item shall be the number of square yards of compacted material in place in the completed course. The amount to be estimated shall be computed by multiplying the finished width of the top course as shown upon the plans or ordered by the Engineer, by the length of the top course measured along the axis of the pavement.

The price bid shall include the furnishing (bituminous material excepted), the heating, placing, rolling and compacting of all materials, together with all other labor and incidental expenses necessary to satisfactorily complete the work.

The furnishing of the bituminous material will be paid for under the appropriate item therefor as shown on the proposal sheet.

Item 54—Top Course—Bituminous Macadam—Mixing Method. Type 2

54.1. Under this item the Contractor will be required to construct a top course consisting of a compacted mixture of broken stone, sand and bituminous material "A" laid to conform to the required grade and cross-section, as shown on the plans and ordered by the Engineer.

54.2. Broken stone for this course shall be of the character specified all of which shall pass a one-half-inch screen and shall be so graded that when combined in a bituminous mixture containing not less than thirty (30) per centum of the sand specified in section 54.3 it shall produce a bituminous mixture coming within the limits specified in section 54.8.

54.3. The sand shall be clean, hard grained and sharp. It shall all pass a ten (10) mesh screen, and shall contain at least fifteen (15) per centum of material retained on a forty (40) mesh screen and at least twenty (20) per centum of material that will pass an eighty (80) mesh screen except as hereinafter provided for. If the sand does not contain the required amount of fine material, approved stone dust may be added to make up the deficiency.

54.4. The bituminous material to be used in this course shall conform with the specifications for bituminous material "A" for Type 2.

54.5. The broken stone and sand shall be heated as directed, before entering the mixer, to between 225 degrees Fahrenheit and 325 degrees Fahrenheit in revolving dryers of an approved type. The broken stone and sand shall be continuously agitated during the heating.

54.6. The bituminous material shall be heated in kettles so designed as to produce an even heating of the entire mass, with an efficient and positive control of the heat at all times. It shall be heated as directed to a temperature between 275 degrees Fahrenheit and 350 degrees Fahrenheit. If heated beyond 350 degrees Fahrenheit either before or during the mixing with the broken stone it shall be rejected.

54.7. The Contractor shall provide a sufficient number of accurate, efficient, stationary thermometers for determining the temperature of the asphalt cement in the kettles.

54.8. When thoroughly heated to the temperature directed, the bituminous material and the broken stone and sand shall be mixed in the following proportions by weight:

Bitumen	from 7 to 11 %
Mineral aggregate, passing 200 mesh	from 7 to 11 %
Mineral aggregate, passing 40 mesh	from 45 to 55 %
Mineral aggregate, passing 10 mesh	from 16 to 25 %
Mineral aggregate, passing 4 mesh	from 8 to 15 %
Mineral aggregate, passing 2 mesh	less than 10 %

the sieves being used in the order named. A mixer shall be used, having revolving blades, and so designed and operated as to produce and discharge a thoroughly coated and uniform mixture of non-segregated broken stone, sand and bituminous material. When discharged the mixture shall have a temperature not more than 325 degrees Fahrenheit and not less than 225 degrees Fahrenheit as directed.

54.9. All defective areas in the cement concrete foundation shall be repaired as directed at least ten (10) days in advance of laying the bituminous concrete. Before laying the bituminous concrete the surface of the foundation shall be dry and thoroughly cleaned.

54.10. The mixture heated and prepared as specified in section 54.8, shall be delivered direct from the mixer to the point of deposition on the foundation in trucks or wagons, provided with canvas covers for retaining the heat. As delivered, the bituminous concrete shall have a temperature of at least 200 degrees Fahrenheit: material having a lower temperature than this shall not be laid upon the foundation. Before the mixture is placed, all contact surfaces of curbs, edgings, manholes, etc., shall be well painted with hot asphalt cement. The hot mixture shall be dumped upon platforms, constructed as directed, and shoveled with hot shovels into position on the foundation. It shall be immediately spread as directed over the foundation course by men experienced in such work, so that when rolled it shall have at no place less than the required thickness and shall be free from surface depressions and irregularities. Joints between hot and

cold materials shall be constructed as directed. The paving shall be done as continuously as practicable, to reduce to a minimum the number of such joints.

54.11. Rollers used on the bituminous concrete shall be well balanced, self-propelled, tandem rollers, weighing between seven (7) and eight (8) tons each. Each shall have a compression under the rear roller of between two hundred (200) and three hundred (300) pounds per linear inch of roll, and shall be provided with an ash pan which shall prevent ashes from dropping into the bituminous concrete or sealing coat.

54.12. The surface of the top course shall be tested with a ten (10) foot straight edge laid parallel with the center line of the road upon any portion of the surface, and any depression or other irregularity exceeding one-half (½) inch [¼" is a better limit] shall be satisfactorily eliminated as directed.

54.13. After the pavement has been satisfactorily finished and has thoroughly dried out, Portland cement shall be dusted over the surface in a quantity sufficient to form a complete film over all parts of the pavement. This film shall remain undisturbed by rain or otherwise until it has set; in case of disturbance before setting, it shall be renewed.

54.14. No top course material shall be mixed or placed between October 15th and May 15th, except by written permission of the Engineer, nor when the air temperature in the shade is below 50 degrees Fahrenheit nor when the foundation is damp or otherwise unsatisfactory.

54.15. The quantity to be paid for under this item shall be the number of square yards of compacted material in place in the completed pavement. The amount to be estimated shall be computed by multiplying the width of top course as shown on the plans or ordered by the Engineer, by the length of the top course measured along the axis of the road.

The price bid for this item shall include the furnishing of the sand; the furnishing, crushing and screening of the broken stone; the heating, mixing, placing and rolling of the broken stone, sand and bituminous material, and the cement film and all work and expense incidental to the completion of the work except the furnishing of the bituminous material, which shall be paid for under the item BITUMINOUS MATERIAL "A" FOR MIXING METHOD, TYPE 2.

Item 55—Bitulithic Pavement

55.1. Under this item the Contractor shall furnish the necessary stone, bituminous material, machinery, labor and other equipment, and shall construct upon a properly prepared foundation a bitulithic pavement composed of an accurately proportioned aggregate of carefully graded broken stone properly heated and mixed with separately heated Warren's Puritan Brand bitulithic cement, placed and rolled and covered with Warren's quick drying bituminous flush coat composition, followed by two coats of hot stone chips thoroughly rolled into the surface.

55.2. The several grades and sizes of mineral aggregate shall be accurately measured in proportions previously determined by laboratory tests to give the best results; that is, the most dense mixture of mineral aggregate and one having inherent stability; heated in a rotary mechanical heater so designed as to keep each batch by itself until heated, or after heating the stone in a rotary mechanical heater to a temperature of about 250 degrees Fahrenheit, it shall be elevated and passed through a rotary screen, having sections with various sized openings. The difference in the width of openings in successive sections shall not exceed one-fourth (¼) inch in sections having openings smaller than one-half (½) inch, and shall not exceed (½) inch, in sections having openings greater than one-half (½) inch. The several sizes of stone thus separated by the screen sections shall pass into a bin containing sections or compartments corresponding to screen sections. From these compartments the stone shall be drawn into a weighing-box, resting on a scale having seven beams. The stone from these compartments shall be accurately weighed, using the proportions which have been previously determined by laboratory tests to give the best results; that is, the most dense mixture of mineral aggregate, and one having inherent stability. If the crushed stone in the wearing course does not provide the best proportions of fine-grained particles, such deficiency must be supplied by the use of not to exceed 25 per centum hydraulic cement, pulverised stone, or very fine sand.

55.3. The mineral aggregate, composed of differing sizes accurately measured or weighed as above, shall pass into a "twin pug" or other approved

form of mixer. In this mixer shall be added a sufficient quantity of Warren's Puritan Brand, bituminous water-proof cement, or bitulithic cement, to thoroughly coat all the particles of stone and to fill all voids in the mixture. The bituminous cement shall, before mixing with the stone, be heated to between 200 degrees and 250 degrees Fahrenheit, and the amount used in each batch shall be accurately weighed and used in such proportions as have been previously determined by laboratory tests to give the best results—that is, to coat all particles of stone and fill the voids in the mineral aggregate. The mixing shall be continued until the combination is a uniform bituminous concrete. In this condition it shall be hauled to the street, and there spread on the prepared foundation to such a depth that, after thorough compression with a steam road roller, it shall have a thickness of two (2) inches. The proportioning of the varying sizes of stone and bituminous cement shall be such, that the compressed mixture shall, as closely as practicable, have the density of solid stone.

55.4. After rolling the wearing surface, there shall be spread over it, while it is still warm, a thin coating of Warren's Quick Drying Bituminous Flush Coat Composition, by means of a suitable flush coat spreading machine, so designed as to spread quickly over the surface a uniform thickness of flush coat composition. This spreading machine shall be provided with a flexible spreading band and an adjustable device for regulating, to any desired amount, the quantity and uniformity of flush coat composition to be spread.

There shall be spread over the flush coat composition, in at least two coats, fine particles of hot crushed stone, in sufficient quantity to completely cover the surface of the pavement. These stone chips shall be spread by means of a suitable stone spreading machine, so designed as to provide a storage receptacle of at least five (5) cubic feet capacity and to rapidly and uniformly cover the surface of the pavement with the desired quantity of stone. This spreading machine shall be provided with an adjustable attachment for regulating uniformly the quantity of stone spread at each operation. The hot stone chips shall be immediately and thoroughly rolled into the surface until it has become cool. The purposes of the flush coat composition and the fine particles of hot crushed stone are to not only fill any unevenness in the surface, but also to make the surface waterproof and gritty, thus providing a good foothold for horses.

On grades a mineral flush coat may be used in place of the liquid flush coat.

55.5. Warren Bros., owners of the patents used in the construction of Bitulithic pavement, have filed with the State Commission of Highways a properly executed binding agreement to furnish any contractor to bid for the work all the necessary surface material mixed and ready for use, and bituminous flush coating cement necessary for coating the wearing surface, delivered on wagons of the Contractor at the mixing plant (which will be located within three miles of the point of use) at a stipulated price per square yard for each contract. Such price for Bitulithic pavement mixture and flush coating composition will include a license to use all the patents required in the construction of the pavement as herein specified.

The filing of a bid under these specifications will be construed as an acceptance of the terms of the license agreement filed by the Warren Bros. Company, at the price fixed in said agreement, which is on file with the secretary of the Commission.

55.6. The quantity of pavement to be paid for under this item shall be the number of square yards of Bitulithic pavement placed in accordance with the plans, or as directed by the Engineer. The bid price shall include the furnishing and placing of all materials, the mixing, spreading, rolling and all labor and incidental expenses necessary to complete the work.

GENERAL SPECIFICATIONS FOR AMIESITE PAVEMENT

Foundation.—The excavation, filling or embankment, drainage and rolling of the sub-base shall be in full accordance with the standard specifications for street or highway paving before placing the foundation, the depth and nature of which is governed by existing conditions of the sub-grade.

The foundation, whether in re-surfacing or new work, shall be, before applying the Amiesite, even and compact and swept clean of all loose dirt and foreign material. New stone, if put on, shall be thoroughly bonded with screenings, sprinkled and rolled hard and uniformly. The foundation must be uniform and be brought up to a true and even grade, parallel to

and —— inches below the elevation of the finished surface of the street or road.

Application.—The bottom course shall be spread in a uniform layer, using blocks or strips to insure an even distribution, then rolled. (Size) Stone used in Amiesite Bottom Course-Graded—¾″ to 1¼″. If any depressions appear, due to foundation not being firm or any other reason, they must be filled with Amiesite and rolled until surface is even and to grade desired.

After the preliminary rolling, the Amiesite top course, made of stone graded from ¼″ to ½″ in size, shall be applied, not less than one inch (1″) deep, loose measurement, and raked to an even depth so as to cover the underlying Amiesite and fill the voids. In no case shall the bottom course be spread over 300′ in advance of the top course, nor shall over 50′ be left uncovered during the night.

The compressed depth of finished Amiesite surface shall be: Preferably not less than 2½ inches.

Rolling.—After the top course has been evenly spread to a true grade, the surface shall be rolled with a standard ten ton road roller until the material is thoroughly compacted and ceases to creep in front of the roller. In rolling the roller must start from the sidelines of the street or road and work towards the center. Care must be taken that the shoulders are firm and solid, as otherwise the surface will iron out to a feather edge and crack. No rolling shall be done unless the Amiesite is free from water.

Surface Finish.—After rolling as called for above, clean, sharp sand or stone dust (Limestone where obtainable) shall be spread in a thin layer and the road may then be immediately thrown open to traffic.

General.—No Amiesite shall be spread when the road-bed contains depressions holding water. The Amiesite must at all times be kept clean. Dirt or other foreign material must not be allowed to mix with, under, or on the Amiesite while being unloaded from cars, spread and rolled.

Should the bottom course become coated or partly coated with dust or dirt before the top course can be applied, the part thus coated must be swept and then given a light application of bituminous cement, that can be applied in a thin coating from a sprinkling pot so constructed that a thin and uniform application can easily be applied.

The Amiesite may be steamed to facilitate its unloading from the cars. Steam pressure shall not exceed fifteen pounds to the square inch. The Amiesite should not be steamed more than fifteen minutes in any one place. This shall be done under the supervision of the inspector in charge.

The Amiesite shall be unloaded from wagons upon iron sheets or boards, so as to insure the material being kept clean and being spread uniformly.

Cross rolling shall be done, when ordered, to equalize the bond and prevent waves in the surface. Care must be taken that the bottom course is not rolled down hard before the top course is applied.

The finished surface of the Amiesite after rolling shall be kept ½″ higher than any permanent elevation, depending upon the traffic to ultimately compress or pound it down to grade.

Grading slopes or shoulders shall not be carried on after the Amiesite course is started until completion of roadway.

The street or road shall be closed to traffic when the Amiesite surface is being applied.

Item 56—Hassam Compressed Concrete Pavement

56.1. Under this item the Contractor shall furnish all materials for and place upon a properly prepared sub-grade or sub-bottom course Hassam Compressed Concrete Pavement of the thickness shown upon the plans or ordered by the Engineer.

56.2. Hassam Compressed Concrete Pavement will be placed on the sub-grade or on the sub-bottom course and shall not be placed until these are in first-class condition as required for macadam pavement.

56.3. Hassam Compressed Concrete Pavement shall consist of a graded No. 3 and No. 4 stone (for the meaning of these numbers see page 720), of an approved quality, spread evenly and gauged by the use of cubical blocks; after rolling and thoroughly compacting with a 10-ton roller, it shall have the required depth and shall conform to the established lines, grades and cross-sections. Where any depressions or irregularities develop in rolling the surface shall be forked over and material added or taken away to the end that a smooth surface shall be provided after re-rolling.

56.4. After the rolling has been satisfactorily completed and the surface

of the broken stone has been brought to the required uniform surface, and before there is any displacement of the stone, the voids shall be filled with a grout consisting of one part Portland cement and two parts of approved sand. The sand shall be of such sizes that it will not separate readily from the cement, when placing the grout, and any batch of grout, when being placed, shall at all times be of a uniform product and of such consistency that it will flow readily but shall not be so wet as to cause a separation of the cement and sand. The rolling shall be continued during the process of grouting and until all the voids are filled.

56.5. The grout shall be mixed in a Hassam Grout Mixer or other mechanical mixer which will properly mix the ingredients and from which they can be deposited without a separation of the cement and sand.

56.6. Immediately after the voids shall have been filled with grout, a thin layer of No. 1 broken stone or fine aggregate shall be spread over the entire surface and rolled until the grout flushes to the surface.

56.7. After placing the surface stone the surface shall not be worked upon or disturbed for a period of ten days, during which time the surface shall be kept thoroughly wet.

56.8. Any cracks either longitudinal or transverse which develop before the acceptance of the work shall be thoroughly cleaned out and filled with acceptable bituminous material.

56.9. The quantity to be paid for, under this item, shall be the number of cubic yards of Hassam Compressed Concrete Pavement incorporated in the work in accordance with the plans or as directed by the Engineer.

The price bid shall include the furnishing and placing of all materials, all grouting, rolling, forms and all labor, appliances, royalties and incidental expenses necessary to complete the work. The amount to be estimated shall be computed by multiplying the cross-section of concrete pavement as shown upon the plans or ordered by the Engineer, by the total length of pavement measured along the axis of the pavement.

Item 57—Cement Concrete Pavement

57.1. Under this item the Contractor shall furnish and place upon a properly prepared sub-grade or sub-bottom course, concrete pavement of the thickness shown upon the plans or ordered by the Engineer.

57.2. Concrete pavement will be placed on the sub-grade or on the sub-bottom course, and shall not be placed until these are in first-class condition, as required for macadam pavement.

57.3. Concrete shall consist of a mixture of Portland cement, No. 1 sand, and broken stone or gravel. All these materials shall conform in all respects to the requirements given under "Materials of Construction," and all the specifications relating to first-class concrete shall apply to work done under this item, in so far as same are not inconsistent with the special specifications given below.

57.4. The concrete shall be mixed in the proportions of one volume of cement to four and one-half volumes of sand and broken stone or gravel. The volumes of sand and broken stone or gravel, shall be measured separately in approved hoppers. The relative proportions of fine and coarse aggregate will be varied slightly, as a result of tests for voids by the Engineer, to the end that resulting concrete shall be as dense as possible. The concrete shall in all cases approximate at 1 : 1½ : 3 mix.

57.5. The coarse aggregate shall consist of a well-mixed product of No. 2 and No. 3 stone or No. 1 and No. 2 gravel. Gravel shall not be used except when it has been submitted by the Division Engineer to the Bureau of Tests, has been approved by the Bureau of Tests, and its use has been approved by the First Deputy Commissioner in writing—and then only under the restrictions laid down under "Materials of Construction." The fine aggregate shall consist of No. 1 sand.

57.6. The concrete shall be mixed in approved mechanical batch mixers. Mixing shall be continued through at least 12 revolutions and until every particle is coated with mortar and until the batch is of uniform color and consistency. After the materials are once wetted the work shall proceed rapidly until the concrete is in place. The quantity of water used shall be as directed by the Engineer and suitable measuring tanks shall be provided by the Contractor so that the same amount of water may be used in the separate batches. No concrete pavement shall be laid when the temperature falls below 35° F.

57.7. Substantial forms shall be placed along the edge of the concrete pavement and shall be set and held true to line and grade.

57.8. Before any concrete is placed, the sub-grade shall be sprinkled sufficiently to dampen it but a muddy condition shall not be allowed. As soon as possible after mixing, the concrete shall be deposited in place and thoroughly spaded and screeded so as to bring the mortar flush to the surface. Especial care shall be taken to keep the concrete uniform and to prevent pockets of stone or mortar.

57.9. Heavy screeds cut to the lines required for the finished surface and resting upon the side forms shall be used for consolidating and screeding the concrete, and the surface, when completed, shall conform to the lines and grades shown upon the plans, and shall be free from depressions or irregularities. No stone shall project above the general surface. All shaping and screeding shall be done before the concrete has taken its initial set. Any concrete which has not been shaped and finished previous to the time of initial set, shall be removed for the full depth of the roadway and replaced with satisfactory concrete.

57.10. If a satisfactory finish can not be obtained with the screed, the screeding shall be immediately followed, and before the cement has taken its initial set, by rubbing down with a wooden float. The men employed for this work shall be competent and experienced and shall work from a platform which rests on the forms or shoulders. The surface, when finished, shall be such that no water will stand on the finished pavement. It shall then be slightly roughened by brooming.

57.11. As soon as the concrete has taken its initial set the surface shall be covered with a one-inch layer of sand or other suitable material of which the shoulders are to be constructed and this shall be thoroughly sprinkled every morning and night, and more often if necessary, so that it will be kept moist for a period of ten days after placing; the material shall then be cleaned from the surface and the road may be opened to traffic if so directed by the Engineer.

57.12. The concrete shall be deposited in sections 30 feet in length, and at the end of each section expansion joints of the type shown on the plans shall be placed. After starting any section, an effort shall be made to complete it at one operation. If for any reason this can not be done, a vertical joint shall be made when the work is stopped and the work completed up to this joint.

57.13. Any cracks, either longitudinal or transverse, which develop before the acceptance of the work, shall be thoroughly cleaned out and filled with acceptable bituminous material.

57.14. The quantity to be paid for under this item shall be the number of cubic yards of concrete pavement incorporated in the work, in accordance with the plans or as directed by the Engineer.

The price bid shall include the furnishing and placing of all materials; all mixing, screeding, finishing, forms, expansion joints and all labor, appliances and incidental expenses necessary to complete the work. The amount to be estimated shall be computed by multiplying the cross-section of concrete pavement as shown upon the plans or ordered by the Engineer by the total length of pavement measured along the axis of the pavement.

Item 58—Lignin or Sulphite Liquor

58.1. Under this item the Contractor shall furnish and apply lignin or sulphite binder at the rate of one-half gallon of binder (not of the mixture) to the square yard.

58.2. A quart sample, from each carload of the material to be used, shall be submitted to the Bureau of Tests for acceptance before it may be used.

This material shall be a neutral or basic liquor secured by the extraction of lignin from organic matter. It shall be concentrated by evaporation at a temperature not exceeding 210 degrees Fahrenheit until it has a specific gravity at 77 degrees Fahrenheit of not less than 1.23. When concentrated to a constant weight at 212 degrees Fahrenheit, it shall have a residue of not less than 45 per cent. It shall contain not more than 9 per cent. of ash. It shall be 99.5 per cent. soluble in cold water.

58.3. After the road has been thoroughly filled and brought to a puddle with water, the application of lignin or sulphite binder shall commence and the puddle continued, using a mixture of one part binder to not less

than three parts water. This puddling shall continue until the road has received a treatment for its full width of one-quarter gallon of the lignin (not of the mixture) to the square yard. After the roadway has set, but not entirely dried out, the balance of one-quarter gallon of the lignin to the square yard shall be applied to 80 per cent. of the width of roadway, using a mixture of one part lignin to two parts water.

58.4. Lignin or sulphite binder shall be applied to the roadway by means of an improved sprinkler which can be regulated so that a uniform distribution is obtained and so that not over one-half of the required amount of binder shall be spread to the square yard on each trip of the sprinkler. The sprinkler shall be equipped with necessary brooms so arranged as to sweep forward any excess material that does not immediately penetrate into the surface.

58.5. The quantity of material to be paid for under this item shall be the actual number of gallons of lignin binder, measured before dilution, actually applied and incorporated in the work to the satisfaction of the Engineer. Binder that has been wasted or that has been applied not in accordance with the requirements of this specification or the orders of the Engineer, shall not be included in this item for payment. The price bid shall include the cost of furnishing hauling, applying and all necessary appliances and expenses incidental thereto.

Item 59—Wood Block Pavement

59.1. Under this item the Contractor shall furnish and place upon a properly prepared foundation wood block of the quality specified where shown upon the plans or ordered by the Engineer.

This pavement shall be placed upon the old macadam, old concrete pavement, new concrete foundation or on other foundation as shown on the plans and ordered by the Engineer.

59.2. The blocks shall be from 6 to 9 inches long and shall average 8 inches; they shall be 3 inches in depth and from 3 to 4 inches in width; but all blocks in one piece of pavement shall be of uniform width. No variation greater than 1/16-inch shall be allowed in the depth and 1/8-inch in the width of the blocks.

59.3. Blocks shall be made from Southern yellow pine, North Carolina pine, Norway pine, black gum or tamarack; only one kind of wood, however, shall be used in one piece of pavement.

Yellow pine block shall be made from what is known as Southern yellow pine, well manufactured, full size, saw butted, all square edges, and shall be free from the following defects:

Unsound, loose and hollow knots, worm holes and knot holes, through shakes and round shakes that show on the surface. In yellow pine timber the annular rings shall average not less than six to the inch and shall be in no case less than four to the inch, measured radially.

Norway pine, gum, North Carolina pine and tamarack block shall be cut from timber that is first-class in every respect, and shall be of the same grade as that defined for the Southern yellow pine.

59.4. The creosote oil with which the blocks shall be treated shall conform to either of the following specifications, designated as "A" and "B."

The preservative to be used under this specification shall be a product of coal gas, water gas or coke oven tar, which shall be free from all adulterations and contain no raw or unfiltered tars, petroleum compounds, or tar products obtained from processes other than those stated.

Specification "A"

The specific gravity shall not be less than one and eight-hundredths (1.08) nor more than one and fourteen hundredths (1.14) at a temperature of thirty-eight (38) degrees centigrade.

Not more than three and one-half (3½) per cent. shall be insoluble by continuous hot extraction with benzol and chloroform.

On distillation, which shall be made exactly as described in Bulletin 65 of the Railway Engineering and Maintenance of Way Association, the distillate, based on water free oil, shall not exceed one-half (½) of one (1) per centum at one hundred and fifty (150) degrees centigrade, and shall not be

less than thirty (30) nor more than forty (40) per centum at three hundred and fifteen (315) degrees centigrade.

The oil shall contain not more than three (3) per centum of water.

Specification "B"

It shall be completely liquid at thirty-eight (38) degrees centigrade, and shall have a specific gravity at that temperature of not less than one and three hundredths (1.03) nor more than one and eight hundredths (1.08).

It shall contain not more than two (2) per centum of matter insoluble by hot extraction with benzol and chloroform.

On distillation, which shall be made exactly as described in Bulletin No. 65 of the American Railway Engineering and Maintenance of Way Association, the distillate based on water free oil shall be within the following limits:

At 210 degrees centigrade, not more than 5 per centum.

At 235 degrees centigrade, not more than 35 per centum.

At 315 degrees centigrade, not more than 85 per centum.

The oil shall yield a coke residue not exceeding three (3) per centum.

The distillate, between 210 degrees centigrade and 235 degrees centigrade, shall yield solids on cooling to 15 degrees centigrade. The preservative shall contain not more than 3 per centum of water.

59.5. The manufacturer of the oil shall permit full and complete inspection and sampling at the factory at which the oil is produced, of all materials either crude or refined, entering into the manufacture of the finished product itself, in order that the materials used can be determined to be in accordance with the foregoing requirements. He shall also submit satisfactory proof of the origin of all materials entering into the composition of the finished product.

Samples of the preservative taken by the inspector from the treating tank during the progress of the work shall at no time show an accumulation of more than 2 per centum of foreign matter, such as sawdust or dirt.

59.6. The blocks shall be treated with the preservative above described, so that they shall contain at least sixteen pounds of the same per cubic foot of timber.

The manufacturer of the block shall equip his plant with all necessary gauges, appliances and facilities to enable the inspector to satisfy himself that the requirements of the specifications are fulfilled.

59.7. Upon the foundation shall be spread a bed of cement mortar at no place less than one-half inch in thickness, composed of one part Portland cement and four parts sand thoroughly mixed dry. This mortar bed shall be struck with a template to a true surface exactly parallel to the top of the proposed pavement surface and three inches below it. This bed shall be sprinkled, immediately in advance of the block laying, with hand sprinklers.

59.8. On the mortar surface prepared as described, the blocks shall be laid with grain vertical and at such angles with the curb as the Engineer may direct. The blocks shall be laid in straight and parallel courses and set snugly together but not driven together. Each course of blocks shall be of uniform width and depth, with end joints broken by a lap of not less than two and one-half inches. Only whole blocks shall be used except in starting courses, cutting closures, or where specially permitted by the Engineer.

Closures shall be carefully cut and trimmed by experienced men, the portion of the blocks used shall be free from defects and the cut end shall have a surface perpendicular to the top of the block and cut at a proper angle to give a close joint. In laying block the pavers must stand on the block previously laid.

After the laying is completed, defective blocks shall be carefully culled out, low blocks raised, the courses carefully aligned and the blocks spaced up. The pavement shall then be rolled by a steam tandem roller weighing not less than two and one-half tons nor more than five tons; the pavement being at the same time lightly sprinkled and the rolling continued until a uniform surface is obtained. Upon the completion of the rolling any defective blocks shall be removed and be replaced with sound blocks, and displaced blocks shall be realigned. The joints in the pavement shall then be immediately filled in the manner hereinafter described. If deemed advisable by the Engineer, portions of pavement laid with blocks which have become "dried out" shall be sprinkled with water at frequent intervals before joints of same are filled.

59.9. After rolling, the blocks shall be flushed with an approved bituminous filler heated to at least 300 degrees Fahrenheit, which shall be poured over the whole surface and well forced into the joints by rubber squeegees. While the bituminous filler is still hot it shall be immediately followed with a thin coating of clean dry sand. Before turning traffic onto the pavement a coating of one-half inch in thickness of dry screened sand shall be spread over the entire surface.

ASPHALTIC FILLER (CITY OF LIMA, OHIO)

After rolling, the surface of the pavement shall be swept clean and the joints between the blocks and expansion joints shall be filled with an asphaltic filler which shall be free from water, coal-tar pitch, or any product of coal or water gas tar. It shall adhere firmly to the blocks, be pliable, at all climatic conditions to which it will be subjected, and conform to the following requirements:

It shall have a specific gravity of not less than nine hundred and sixty-five thousandths (0.965) at seventy-seven (77) degrees Fahrenheit.

It shall have a melting point of not less than one hundred and ten (110) and not more than one hundred and sixty (160) degrees Fahrenheit.

It shall have a penetration of not less than twenty (20) nor more than fifty (50).

The bitumen of the asphaltic filler shall be soluble in carbon tetrachloride to the extent of at least ninety-eight (98) per cent.

The asphaltic filler shall be heated to a temperature of not less than two hundred and eighty (280) degrees nor more than three hundred and fifty (350) degrees Fahrenheit, and shall be applied in such a manner that all spaces between the blocks will be completely filled, the temperature of heating to be varied within these limits according to the nature of the asphaltic filler used and at the discretion of the City Engineer. In applying the asphaltic filler care must be taken to use the least amount necessary to properly fill the joints and hold the top dressing. The blocks must be dry at the time of the application of the filler.

PITCH FILLER (CITY OF LIMA, OHIO)

After rolling, the surface of the pavement shall be cleaned and the joints between the blocks and expansion joints shall be filled with a "straight run" paving pitch obtained from gas-house tar. No pitch from coke-oven tar shall be used. It shall be of such quality and consistency as will be approved by the City Engineer. The pitch shall contain not less than twenty (20) per cent. nor more than thirty (30) per cent. of free carbon, and shall have a melting point at a temperature of not less than one hundred and twenty (120) degrees and not more than one hundred and thirty (130) degrees Fahrenheit. The pitch must be used at a temperature of not less than three hundred (300) degrees and not more than three hundred and fifty (350) degrees Fahrenheit. In applying the pitch, care must be taken to use the least amount necessary to properly fill the joints and hold the top dressing.

SAND FILLER (CITY OF LIMA, OHIO)

After rolling, the surface of the pavement shall be swept clean and the joints, except as hereinafter provided, between the blocks shall be filled with clean, warm, fine sand, which shall be swept into the joints until the same are completely filled.

The expansion joints and joints between the blocks in a space of two (2) feet in width adjacent to the gutters, a space of four (4) feet wide in the middle of the roadway and around all covers to sub-surface improvements shall be filled with a "straight run" paving pitch obtained from gas-house tar. No pitch from coke-oven tar shall be used. It shall be of such quality and consistency as will be approved by the City Engineer. The pitch must be used at a temperature of not less than three hundred (300) degrees and not more than three hundred and fifty (350) degrees Fahrenheit. The pitch shall contain not less than twenty (20) per cent. nor more than thirty (30) per cent. of free carbon and shall have a melting point at a temperature of not less than one hundred and twenty (120) degrees and not more than one hundred and thirty (130) degrees Fahrenheit.

ALTERNATIVE

For the purpose of automatic expansion and the prevention of slipperyness, alternate bids will be received for Creosote Lug Blocks, or their equal.

On one end of each block there shall be one, and on one side of each block there shall be two ribs or projections extending the full depth of the block, and such ribs or projections shall be an integral part of the block.

Such ribs or projections shall be of the size and shape and placed in such position on the block as the Engineer may determine.

In all other respects such blocks shall conform to these general specifications. Should there be any deviation therefrom, the contractor shall submit complete specifications of the kind of block he wishes to bid on and the method of manufacturing the same.

59.10. The quantity to be paid for under this item shall be the number of square yards, including expansion joints, of pavement laid in accordance with the plans and as directed by the Engineer.

The price bid shall include the furnishing and placing of the mortar bed, wood block, bituminous filler and sand surfacing and all other labor and incidental expenses necessary to complete the work.

Item 60—Asphalt Block Pavement

60.1. Under this item the Contractor shall furnish and place upon a properly prepared foundation asphalt block of the quality specified where shown upon the plans or ordered by the Engineer. This pavement shall be placed upon the old macadam, old concrete pavement, new concrete foundation or on other foundations as ordered by the Engineer and shown upon the plans.

60.2. The blocks shall be five inches in width, by twelve inches in length, by two inches in depth, and a variation of more than one-fourth of an inch in length and one-eighth of an inch in width or depth from these dimensions will be sufficient ground for rejecting any block.

60.3. The blocks shall consist of the following materials:

Asphaltic cement.
Crushed trap rock or other approved crushed rock.
Inorganic dust.

The rock used in the blocks must be crushed so that every particle will pass a screen of one-fourth of an inch mesh. The blocks shall receive a compression in the moulds of not less than one ton per cubic inch of material in the blocks, and must weigh not less than ten and one-half pounds per block. The blocks shall have a specific gravity of not less than 2.40, and after having been dried for twenty-four hours at a temperature of 150 degrees Fahrenheit, they shall not absorb more than 1 per centum of moisture when immersed in water for seven days. Whatever the character of the asphalt used, the block shall yield not less than 6½ per centum of bitumen, when extracted with carbon bisulphide.

The inorganic dust, or filler, shall be produced from sound limestone or other approved material, and shall be powdered to such a fineness that all of it shall pass a thirty mesh sieve and not less than 50 per centum of it shall pass a 200 mesh sieve. Sufficient inorganic dust shall be used to give a minimum percentage of voids in the block, and provide a sufficient medium for absorbing the asphaltic cement.

60.4. The asphaltic cement shall be composed of natural or oil asphalt, and asphaltic oil, as approved. This asphaltic cement shall be of acceptable consistency and quality.

The material shall have a specific gravity of at least 0.98 at 77 degrees Fahrenheit. Its penetration shall be not more than ten mm. when tested for five seconds at 77 degrees Fahrenheit, with a No. 2 needle weighted with 100 grams. When twenty grams are heated in a hot air oven in a flat-bottom dish two and one-half inches in diameter at 325 degrees Fahrenheit for five hours, the loss in weight shall not be more than eight per centum. It shall show an open flash point not less than 325 degrees Fahrenheit. Its solubility at air temperature in chemically pure carbon disulphide shall be at least sixty-six per centum.

60.5 Upon the foundation shall be spread a bed of the thickness shown upon the plans, composed of one part Portland cement and four parts sand, thoroughly mixed.

This mortar bed shall be struck with a template to a true surface, exactly parallel to the top of the proposed pavement surface and two inches below it

This bed shall be sprinkled immediately in advance of the block laying with hand sprinklers.

The blocks shall be laid while the mortar is fresh and before it has taken its initial set. All depressions and other irregularities in the surface shall be corrected by the Contractor immediately.

The blocks shall be laid by the pavers standing upon the blocks already laid and not upon the bed of mortar.

The blocks shall be laid at right angles with the line of the street, and in such a manner that all longitudinal joints shall be broken by a lap of at least four inches. The blocks shall be so laid as to make the lateral joints as tight as possible, consistent with keeping a good alignment of the courses across the street. When thus laid the blocks shall be immediately covered with clean, fine sand, perfectly dry, and screened through a one-eighth inch screen. This sand shall be spread over the surface and swept into the joints and be allowed to remain on the pavement not less than thirty days or for such time as the action of the traffic on the street shall have thoroughly ground the sand into all the joints.

60.6. The materials incorporated into blocks shall be approved by the Engineer, and samples of all materials shall be sent to the Bureau of Tests and they shall pass the tests required by this Bureau for these materials.

60.7. The method of work and materials used shall at all times be subject to the inspection and supervision of the Engineer or his representative upon the work.

60.8. The quantity to be paid for under this item shall be the number of square yards of asphalt block laid in accordance with the plans or as directed by the Engineer. The price bid shall include the furnishing and placing of all materials, mortar bed, and all labor and incidental expenses necessary to complete the work. Where placed upon old concrete foundation to receive the mortar bed will be paid for under item "CLEANING OLD PAVEMENT" or item "SCARIFYING AND RESHAPING OLD MACADAM."

Item 61—Brick Pavement (Sand Cushion Type)

61.1. Under this item the Contractor shall furnish and place the number of square yards of brick pavement required in accordance with the plans or as ordered by the Engineer. The item will include the furnishing and placing of all the block, sand cushion, grout, expansion joints and all material, labor and other expenses incidental thereto but will not include the concrete foundation, edging, curbing, manholes, catch basins, etc., which will be paid for under the especially designated items therefor.

61.2. All bricks or blocks used must be vitrified and especially burned for street paving and of the very best quality as regards hardness, dimensions, toughness, straight lines and non-absorption of water.

61.3. The paving bricks shall be subjected to modulus of rupture test and to abrasion tests conducted by the Commission in the manner and with rattlers of the type adopted February 7, 1911, by the National Paving Brick Manufacturers Association. One sample shall be tested for every two hundred thousand (200,000) bricks and less than this when conditions warrant. An average loss in weight in a rattler test exceeding twenty-four (24) per centum, or an average absorption of three and one-half ($3\frac{1}{2}$) per centum of water shall cause the rejection of the total quantity that the test represents, provided, however, that if permitted the bricks may be carefully reculled, and new samples taken and tested. If this second test passes the requirements, the bricks represented by it may be used. If this second test fails, no further test shall be permitted but the entire lot shall be rejected. To ensure the furnishing of bricks of uniformly acceptable quality, any "brand" of brick shall be rejected and shall not be further considered if three lots, each of ten thousand (10,000) bricks or more, offered consecutively for acceptance tests, fail to meet the requirements for this section without reculling them.

Modulus of Rupture.—When tested on edge as laid on the pavement, the modulus of rupture shall be not less than two thousand (2000) pounds per square inch. Computed by formula $R = 3\frac{WL}{2bd^2}$ in which R is the modulus of rupture in pounds per square inch, L the length between supports in inches (=6 inches), b and d the breadth and depth in inches, and W the load in pounds, which produces rupture.

All the above tests will be made by the Bureau of Tests of the State Commission of Highways.

61.4. On grades of 5 per centum or over an approved special form of block suitable for steep grades shall be used.

61.5. The size of the brick shall be 3½ inches in width by four inches in depth by 8½ inches in length, and shall not vary from these dimensions more than one-eighth inch in width or depth nor more than one-half inch in length. Bricks of a given brand shall not vary among themselves more than ⅛-inch in depth nor more than ⅛-inch in width nor more than ½-inch in length in any one shipment. If the edges are rounded the radius shall not be greater than 3/16 of an inch. One side shall contain lugs of such dimensions that transverse joints will not be less than 3/16 of an inch nor more than ¼-inch in width. Each end shall contain a semi-circular groove of ⅛ to ¼-inch radius, or a bulge or at least 1/16 inch. The grooves shall be horizontal, and shall match perfectly when the bricks are laid in the finished pavement. Bricks in any course shall not vary in width by more than ⅛ inch.

SAND CUSHION

61.6. Not less than ten days after the concrete foundation has been completed, there shall be laid a bed of clean Cushion Sand as described under "Materials of Construction," which shall be one and one-half inches thick after being rolled with a roller weighing 150 pounds per foot of width. Before being rolled this bed of sand shall be brought to the proper elevation and crown as shown on plans by a template of a shape and size satisfactory to the Engineer. After being rolled all irregularities of the surface shall be eliminated and the sand cushion shall be brought to the exact form and section by the use of lutes or hand templates.

EXPANSION JOINT

61.7. Longitudinal expansion joints shall be placed alongside each curb or edging, and shall be one of the following types:

Premolded Type, requiring no heating or pouring at the place of insertion. These expansion joints shall be of the proper thickness and width, as specified, made in convenient lengths ready for use. The joints shall be placed as the paving progresses, and shall rest directly on the sand cushion. The expansion joints shall be composed *entirely* of a high grade asphalt, and shall pass the following tests:

Specific gravity	.985	to	1.002
Melting point	235°	to	265° F.
Loss on heating for 5 hours at 325° F	.0 %		
Bitumen soluble in carbon disulphide	99.5 %	to	99.9 %
Bitumen soluble in carbon tetra-chloride	99.4 %	to	99.8 %
Bitumen soluble in Be. Naphtha	.	to	%
Penetration at 32° F	25	to	35
Penetration at 77° F	40	to	50
Penetration at 115° F	65	to	75

Poured Type.—This type shall be provided for by placing alongside each curb or edging wooden strips with metal wedge shape pieces dropped over the top of the boards and between the board and the curb every three feet apart to facilitate the removal of the boards, or, by using two planed wedge-shaped strips so cut that when placed together in reverse positions their total section shall be rectangular and of a thickness and depth equal to the thickness and depth of the required expansion joint. The strip placed next to the curb shall be set with the wide edge up. These expansion joint forms shall be set next to the curb on a true grade with all end joints tight, and be pressed into sand so that their tops shall be one-quarter inch below the top surface of the pavement blocks before rolling. The two strips comprising the joint form shall break joints.

The thickness of longitudinal expansion joints shall be as called for by the plan.

61.8. On the sand cushion prepared as in section 61.6 the blocks shall be carefully set on edge with the best edge up, shall be laid straight at and right angles to the edging line, except at road intersections, where they shall be laid at such angles as directed by the Engineer. All block shall be laid with the lugs in the same direction, joints shall be close and at right angles to the tops and sides. Each alternate course shall be commenced with a half brick. No half bricks or bats shall be used except at the ends of courses. All joints shall be broken with a lap of not less than three (3) inches.

All brick shall be clean when placed in the pavement. Brick which in the opinion of the Engineer are not satisfactorily clean, shall be washed before being placed.

In no case shall the sand cushion in front of the pavement be disturbed or walked on during the laying of the blocks.

61.9. After a sufficient number of blocks have been laid, all soft, broken or badly misshapen blocks shall be marked by the inspector and removed. Any blocks slightly spalled or kiln-marked shall be turned over, ,and should the opposite face be acceptable, it may be replaced in the pavement, otherwise, it must be removed.

In laying block pavement, the inspector shall keep the blocks culled, and the Contractor shall make the necessary changes and replacements so that the work shall at all times be ready for grouting within 300 feet from the blocklaying.

GROUTING

61.10. After all objectionable blocks have been removed from the pavement and all replacements have been made, the pavement shall be swept clean and thoroughly rolled with a self-propelled tandem roller weighing not over five tons and not less than three tons. Horse rolling shall not be permitted. This rolling shall start along the outside edges and progress toward the center. It shall then be rerolled diagonally both ways until the surface is even. After final rolling the pavement shall be tested with a ten-foot straight edge laid parallel with the curb, and any depression exceeding one-quarter inch shall be corrected and brought to the proper grade. All blocks disturbed in making replacements or correcting depressions shall be settled into place by ramming or by rerolling. Each section of pavement must be acceptable to the Engineer before the grouting on that section may be commenced.

61.11. Grout for filling the joints of brick or block pavements shall be composed of one part Portland cement and one part Grout Sand.

61.12. The box for mixing this grout shall be about four feet eight inches long, two feet six inches wide and one foot two inches deep, supported on legs of different lengths in order that the mixture shall readily flow to the lowest corner, which shall not be more than six inches above the pavement. Approved mechanical grout mixers may be used.

61.13. The mixture, not exceeding one sack of cement together with a like amount of sand, shall be placed in the box and mixed dry, until the mass assumes a uniform color. Water shall then be added, forming a liquid mixture of the consistency of thin cream for the first coat and slightly thicker for each succeeding coat. From the time the water is applied until the last drop is removed and floated into the joints of the pavement the mixture must be constantly agitated.

61.14. The brick shall be wet to the satisfaction of the Engineer before any grout is placed. The grout shall be removed from the box to the street surface with a scoop shovel and immediately swept into the joints, the mixture in the box being constantly agitated while this is being done.

The work of grouting shall proceed for the entire width of the pavement. When sufficient time has elapsed for the grout to thoroughly penetrate all the joints, but before the cement has attained its initial set, the section treated shall be gone over a second time in the same manner, care being taken to thoroughly fill all joints from the bottom flush with the top of the block. If necessary to secure flush joints, a third, fourth or fifth coat of the grout shall be swept in and smoothed off with a suitable squeegee.

Care shall be taken to so conduct the grouting that no part of any joint will receive an application of the second grout until the first is satisfactorily completed, nor of the third until the second is completed, etc. To insure this result metal strips 1-16 in. by 6 in. by 3 ft. must be inserted, for the full length of the joint, at work intervals; all of the several applications of grout must be completed up to this joint before any grouting is begun on the other side of it.

61.15. After the joints are thus filled flush with the top of the blocks and sufficient time for hardening has taken place, so that the cover coat will not absorb any moisture from the grout, one inch of suitable material shall be spread evenly over the entire surface, and be kept moist for a period of at least ten days and until the grout has thoroughly set.

During this period the section grouted must remain absolutely free from disturbance or traffic of any kind. After 30 days from the spreading, this cover coat shall be completely removed.

EXPANSION JOINTS

61.16. In case the poured type of expansion joint is used, after the grout has set but within thirty-six hours after its application the expansion joint forms shall be withdrawn and the space thus formed thoroughly cleaned and a bituminous filler having a melting point not less than 120 degrees Fahrenheit nor more than 140 degrees Fahrenheit shall be immediately poured into place at a temperature not less than 200 degrees Fahrenheit.

61.17. If required, transverse expansion joints shall be constructed of the materials and in the manner prescribed by the Engineer.

61.18. The quantity of pavement to be paid for under this item shall be the number of square yards placed in accordance with the plans or directions of the Engineer. The price bid per square yard shall include the sand cushion, paving block, grout, material for expansion joint, sand covering, sprinkling, and all other labor, materials and incidentals necessary to satisfactorily complete the work.

The amount to be estimated under this item shall be computed by multiplying the actual width of pavement, including expansion joints, by the total length of pavement measured along the axis of the road and parallel to the surface.

DUNN WIRE-CUT LUG BRICK COMPANY

CONNEAUT, OHIO

SPECIFICATIONS

SUGGESTIONS FOR THE CONSTRUCTION OF A VITRIFIED BRICK WEARING SURFACE ON CEMENT-SAND BED-STREETS AND HIGHWAYS

General.—The durability of a brick pavement depends upon three essentials:

1. Good Design.
2. Good Material.
3. Good Construction.

Design.—The specifications should clearly and concisely cover all the integral parts of the work viz.: sub-grade, drainage, foundation, brick wearing surface, curbing, etc.

The specifications for the sub-grade should insure a sub-grade free of ground water, unyielding, of uniform density and of proper grade and cross sections. The drainage of all underground water should be given careful consideration and means specified to remove same from the sub-grade.

The type of foundation and its thickness depend largely on local conditions the nature of the subsoil, the amount of traffic, and the cost of materials. The foundation should be designed to carry and distribute the load placed upon it and should be no deeper than is necessary to do its work. Its upper surface should be smooth, and of uniform distance below the surface of the finished pavement. A foundation of 1-3-6 concrete is the best type for use under a brick wearing surface.

A cement-sand bed one inch deep should be considered by the engineer as one inch of the foundation; that is: if a five inch foundation is designed, the concrete should be only four inches thick, the cement-sand bed constituting the other inch.

The crown of the brick wearing surface should be light. A straight crown of one-quarter inch to a foot is recommended.

Premolded or prepared bituminous strips the depth of the brick should be used for longitudinal expansion joints. No transverse expansion joints should be used; but a substantial header, either of stone or concrete, should be used at the end of the pavement and at all street and alley intersections.

The use of a combined concrete curb and gutter should be avoided, for it brings the longitudinal expansion joint in the way of traffic, causing a rapid wearing away of the concrete joint.

On highway work the use of steel forms to hold the bricks until the same are grouted is recommended. The cement-sand bed will bind the brick wearing surface and the concrete foundation together, requiring no flush edging, thus saving considerable expense.

Materials.—The specifications should describe the best materials available, and prescribe means for the testing of same. Special care should be used in selecting the grouting sand. It should not be too fine but well graded.

The brick for the wearing surface should be standard Wire-Cut Lug brick with bulged ends. The specifications should not leave it to the contractor to say which style of brick shall be used, but should specify the shape of brick which the engineer considers will make the most durable pavement. Wire-Cut Lug brick are made by independent, competing companies and are marketed at the same price as the repressed brick. Their rough bonding surfaces, their square edges and their uniform lugs have proved their superiority under service and engineers are specifying them exclusively, knowing they will obtain a high grade paving brick, made on engineering lines.

Wire-Cut Lug brick are made the standard depth, four inches, but if so specified can be made three and one-half inches or three inches in depth. These shallow brick are particularly adapted for use on a cement-sand bed as their structural features give exceptional strength to the bond, and their use insures a considerable saving in material, freight and haulage.

High grade Portland cement should be specified, especially for the grout and cement-sand bed.

Construction.—All materials should pass a rigid inspection. The paving brick should be tested at the plant where they are made. All Wire-Cut Lug brick companies have a standard rattler which is at the service of the testing engineer. All cement should be tested.

Good construction is obtained by close inspection, and the inspector should always be on the work.

The interpretation of the specifications shall be made by the engineer, and materials, manner of testing, and equipment for doing the work, should meet with his approval.

In the preparation of the cement-grout filler, the sand should be carefully selected, and should be well graded and not too fine. The amount of water necessary to obtain the proper consistency should be determined, and so regulated as to obtain the same amount for each batch of the filler. Too much water will cause separation; too little water will cause a bridging of the joints.

SPECIFICATIONS FOR THE BRICK WEARING SURFACE

Brick.—The contractor shall submit samples and name the brands of brick with prices respectively upon which he submits bids. The brick shall be of the quality and size commercially known as wire-cut lug vitrified paving brick. They shall be reasonably straight, uniform in size, texture and shape and shall be hard, tough, evenly burned and thoroughly annealed. When broken, the brick shall show a uniform fracture, free from lime, marked laminations and other defects which would tend to depreciate their value as a paving material. They shall have square edges and shall have one fairly straight face, and one side of the brick shall be provided with four (4) projections, which shall not project more than one-fourth (¼) of an inch or less than one-eighth (⅛) of an inch. Each end shall have a bulge of at least one-sixteenth (1/16) of an inch. All brick so distorted as to lay unevenly in the pavement shall be rejected.

The standard size of paving brick shall be three and one-half (3½) inches in width, four (*4) inches in depth, and eight and one-half (8½) inches in length, and shall not vary from these dimensions more than one-eighth (⅛) of an inch in width or depth, nor more than one-quarter (¼) of an inch in length.

Inspection.—All brick shall be subject to thorough inspection before and after laying and rolling. Factory inspection of brick including the rattler test shall be made if in the judgment of the engineer it be expedient.

Test.—The bricks shall not lose of their weight more than 24 per cent. after being submitted to the Standard Rattler Test, to be made under the specifications, in the manner and method and with a rattler, together with records thereof, as adopted by the American Society for Testing Materials at their annual meeting in 1915.

Cement-sand Bed.—Upon the foundation as prepared there shall be spread a bed of cement and sand of uniform density to the depth of one (1) inch and in the proportion of one cement and four sand. The cement and sand shall be thoroughly mixed dry in a mixer until a uniform color is obtained.

The cement-sand bed shall be carefully shaped to a true cross section, parallel with the finished pavement, by means of a template covering at least

*If local conditions justify, the depth of the brick may be made three and one-half (3½) or three (3) inches.

one-half (½) of the width of the brick work, and so made as to be easily drawn over the curb or guide rails set to the proper elevation. The operation of shaping the cement-sand bed for the brick is considered of prime importance in securing the desired evenness in the surface of the finished pavement.

Expansion Joints.—Expansion joints shall be placed parallel with and at each curb line and extend across each street and alley intersections. It should be one-half (½) of an inch in width for streets less than twenty (20) feet wide; three-fourths (¾) of an inch for streets from twenty (20) to thirty (30) feet wide, and one (1) inch in width for streets wider than thirty (30) feet. This joint must extend to the depth of the brick.

A premolded or prepared bituminous strip which will be unaffected by the action of water and will remain pliable at all temperatures to which it may be subjected shall be used for this purpose. The material should be made into strips of suitable length and of the required depth and thickness and shall be placed in the pavement with the ends closely joined as the bricks are being laid.

Delivery of Brick.—Before the grading is finished the brick shall be hauled and neatly piled without the curb line in sufficient quantities to complete the brick surface. Clamps or conveyors may be used in connection with this work, but the brick shall not be dumped from wagons nor shall they be thrown from wagons to piles, or from cars to wagons, nor shall they be piled in any location where they are likely to become bespattered or covered with mud or otherwise injured, unless thoroughly protected.

In delivering the brick from the piles for placement in the street, no wheeling in barrows will be allowed on the brick surface. The brick shall be so arranged and carried on a pallet, or conveyor, that when delivered to the dropper each brick, in the regular operation of placing upon the cement-sand bed as prepared, will naturally lie with the projections in the same direction and with the best edge uppermost.

Brick Laying.—Upon the cement-sand bed as prepared the brick shall be immediately laid with the best edge up, the projections in one direction, and with the courses straight and at right angles to the center line of the pavement, except in the case of hillside brick which are to be laid parallel thereto. All joints must be broken at least three (3) inches; and the courses straightened by tapping lightly with a sledge on a four by four inch timber, three (3) feet in length, provided for that purpose. Nothing but whole brick shall be used except in starting and finishing courses, or in such cases as may be directed by the engineer. The cutting and trimming of the brick shall be done by experienced men. For closures, nothing less than three (3) inch bats shall be used; and the fractured ends laid towards the center of the pavement. Broken and chipped brick suitable for batting shall be used so far as practical in obtaining the necessary half brick for breaking courses and making closures, instead of breaking otherwise whole and sound brick. All brick when laid shall be clean and kept clean and entirely free from dirt or other foreign matter until the pavement is completed. All the work of brick laying shall be done over the brick already laid. The disturbing of the prepared cement-sand bed is prohibited. As soon as any surplus of delivery of brick is ascertained, they shall promptly be moved forward for use.

After the brick have been laid, the chips shall be swept from the street, all soft brick removed, and those badly broken, badly spawled or misshapen shall be turned over or removed by the contractor. Brick slightly chipped on corners, otherwise good, shall be accepted. All rejected brick, suitable for batting in, shall be carried forward and used for that purpose; the remainder shall be placed in separate piles along the street. The inspector shall keep the brick culled and the contractor shall make the necessary changes and replacements so that the work at all times shall be ready for the grouting within fifty (50) feet of the brick laying.

Rolling.—Immediately after the brick in the pavement have been inspected and the surface of the pavement swept clean, it shall be rolled with a self-propelling tandem roller, weighing approximately three (3) tons, in the following manner; the rolling will commence near the curb or edging line, at a slow pace and continue back and forth until the center of the pavement is reached, then pass to the opposite curb or edging line and repeat in the same manner to the center of the street. After the first passage of the roller the pace may be quickened. The pavement shall then be rolled transversely at an angle of forty-five (45) degrees; repeat the rolling in like manner in the opposite direction, then roll parallel with the curb or edging line until the surface is smooth.

Before this last rolling takes place all broken or injured brick must be taken up and replaced with acceptable ones. Portions of the pavement naccessible to the roller shall be tamped to grade by the use of a hand tamper applied upon a two-inch plank.

After the final rolling the surface shall be tested with a ten (10) foot straight edge laid parallel with the center line of the pavement and any depressions exceeding one-quarter (¼) of an inch shall be taken out.

All brick laid shall be rolled ready for grouting at the end of the working day.

Cement Grout Filler.—The cement grout used in filling the joints in the brick shall consist of one (1) part of cement and one and one-half (1½) parts of sand.

The cement shall meet the requirements of the Standard Specifications for Portland Cement of the American Society for Testing Materials, adopted August 16th, 1909, with amendments and additions thereto adopted by said Society.

The sand for the cement-sand bed and the grout filler shall be composed of clean, sharp, well graded quartz grains and shall not contain more than ; per cent. of clay or silt. The grains shall be such size that all will pass a No. 12 sieve and that not more than 40 per cent. will pass a No. 50 sieve.

As soon as the pavement is rolled and before the filler is applied the pavement shall be thoroughly saturated with water so as to insure the hardening of the cement-sand bed.

The cement and sand for grouting in correct proportions shall be thoroughly mixed dry until the mass assumes a uniform color. From this mixture a small batch not exceeding two cubic feet shall be placed in a suitable box or a machine especially adapted for that purpose. Slowly add water and thoroughly mix until the mixture is of such a consistency that it will readily flow into the joints without separation. Ample time must be taken in preparing this liquid mixture, first making a plastic mortar, then gradually thinning by mixing and slowly adding water; continue the mixing until all is removed and applied to the surface in small quantities. The application should be continued until the joints appear to be filled. Any surplus material remaining on the bricks shall then be swept into the joints. Extreme care must be taken that the joints are not cemented over and that the filler extends down to the bottom of the brick.

After the first coat has had a chance to settle and before the initial set develops, a second coat shall be applied in a similar manner with a somewhat thicker grout. After this application has had time to settle and before the initial set takes place, the pavement shall be finished to a smooth surface with a squeegee having a rubber edge which shall be worked over the brick at an angle with the joints—thus leaving them entirely filled.

The contractor shall provide thin metal strips one-sixteenth (1/16) of an inch by six (6) inches by three (3) feet long and insert same in the brick joints across the street when closing up a stretch of grouting at work intervals, so that the grouting will end in a vertical joint. These strips must be taken out when the grout becomes stiff and before the initial set.

Protection of Filler.—After the surface has been thoroughly inspected and if approved, and sufficient time for setting has taken place so that a coating of sand or earth will not absorb any moisture from the cement mixture, the surface shall be covered with one (1) inch or more of sand or earth to prevent too rapid drying of the filler. This shall be kept moist for at least four (4) days, and no traffic shall be allowed on the street for a period of at least fifteen (15) days.

Hillside Brick.—On grades when ordered by the engineer standard Wire-Cut Lug hillside brick shall be used. These brick shall in quality and test conform to the requirements of these specifications.

The general method of constructing a Wire-Cut Lug hillside pavement shall conform to the standard specifications, except that the bricks shall be laid longitudinally instead of transversely. They shall be grouted in the manner specified for brick pavements except that all the grout in the surface grooves of the Wire-Cut Lug hillside brick shall be broomed out before it shall have time to set up (care being taken not to disturb the grout in the longitudinal joints). This brooming should be done transversely with a rattan broom.

Notes.—We strongly advise the use of a small mixer properly equipped for applying the grout. This mixer should be used for the first application, and a suitable box for the second application. When boxes are used the grout shall be removed from same with scoop shovels.

Item 62—Stone Block Pavement

62.1. Under this item the Contractor shall furnish and place upon a properly prepared foundation Stone Block pavement of the quality specified below, where shown upon the plans or directed by the Engineer.

The item will include the furnishing and placing of all the block, sand cushion, grout, expansion joints and all material, labor and other expenses incidental thereto but will not include the concrete foundation, edging, curbing, manholes, catch basins, etc., which will be paid for under the especially designated items therefor.

62.2. The dimensions of the blocks shall be as follows: Not less than six inches nor more than twelve inches long on top, not less than three and one-half inches nor more than four and one-half inches wide on top, and not less than four inches nor more than five inches deep. They shall be dressed so that after laying, no measurement of any joint shall show a width of more than one-half inch for a depth of one inch, or a width of more than one inch in any part of the joint. The head of the block shall be so cut that it shall not have a depression in it more than three-eighths inch deep, and the edges and corners must be full unchipped and unbroken. All blocks shall be sorted and laid in straight courses of uniform width and depth.

62.3. The blocks shall be of stone of medium sized grain showing an even distribution of constituent material. They shall be of uniform quality and texture, without seams, scales or disintegration, and free from an excess of mica or feldspar. They shall be made from rock which when tested in the Deval Rattler will show a "coefficient of wear" of more than 7 and less than 14. All blocks for any one contract shall be from the same quarry unless otherwise directed.

62.4. On the prepared foundation, sufficient clean Cushion Sand as described under "Materials of Construction" on page 719, shall be spread to such a thickness that after the pavement has been thoroughly rammed or settled the sand under the block shall be nowhere less than one inch thick.

On the sand cushion above specified, the blocks shall be set vertically on edge in close contact with each other, and in straight rows across the road at right angles to the curb, except at intersections, where the angle of the rows with the curb shall be varied to meet the conditions. Blocks in adjoining rows shall be set to break joints not less than three inches. All blocks shall be set so that when thoroughly rammed or settled to a firm, unyielding bearing, they will then be true to lines, grades and cross-sections, and have no joints greater than the maximum allowable. All depressions or irregularities in the surface shall be corrected to the satisfaction of the Engineer. Only practiced and competent pavers shall be employed in laying the blocks.

After the blocks are laid, sufficient approved clean gravel shall be spread over the surface and swept into the joints so as to fill the latter to a depth of about two inches from the bottom. The blocks shall then be thoroughly rammed or rolled until firm, even and true to the lines, grades and cross-sections.

Approved expansion joints shall be provided along the curb as may be required and shall be filled with the same quality of filler as is specified for expansion joints in brick pavements. Portland cement grout mixed in proportions of one part cement and one part sand shall then be poured into the joints until the grout flushes to the surface of the pavement. The grout shall be broomed when required, and the pouring and brooming shall be continued until all the joints are thoroughly filled, and the grout is even with the highest part of any and all blocks. Sprinkling or otherwise wetting the blocks before grouting shall be done when atmospheric or other conditions require this precaution to be taken.

62.5. After grouting shall have been completed and the grout shall have sufficiently hardened, a coating of suitable material about one inch deep shall be spread over the whole surface of the grouted pavement, and the road shall then be sprinkled with water. This covering shall be kept wet, and no travel of any kind shall be allowed on the completed pavement for at least seven days thereafter, nor until the grout shall have thoroughly set, when the covering shall be completely removed.

62.6. The quantity to be paid for under this item shall be the number of square yards, including expansion joints, of pavement laid in accordance with the plans and as directed by the engineer.

The price bid shall include the furnishing and placing of all materials, the spreading of sand cushion, and laying, ramming or rolling, grouting, surfacing and all labor and incidental expenses necessary to complete the work.

MEDINA SANDSTONE BLOCK PAVEMENT

(CITY OF ROCHESTER, N. Y., SPECIFICATIONS, 1911)

e grading, subwork, and curbs having been completed as herein speci-
ınder the proper headings, the work of laying the concrete foundation
›aving will then proceed.

:oncrete foundation six (6) inches thick, of Portland cement, as speci-
n the bidding sheet and shown in plans, will be laid in accordance with
ipecifications herein contained. The surface will be eight (8) inches
r the finished pavement and parallel thereto, or seven (7) inches if a
'5) inch block is specified.

.e surface to be kept wet until covered with sand, and, at least, thirty-
ı6) hours shall be allowed for the concrete to set before the pavement is
When connection is to be made with any layer set, or partially set, the
of such layer must be broken down, shall be free from dust and properly
so as to make the joints fresh and close. On this concrete foundation
be laid a bed of clean, sharp sand, perfectly free from moisture (made so
rtificial heat if deemed necessary), not less than one (1) inch thick, to
lepth necessary to bring the pavement and crosswalks to the proper
e when thoroughly rammed.

›on this bed of sand, the stone blocks and crosswalks must be laid. The
: blocks are to be laid in straight courses at right angles with the line
ıe street, except in intersections of streets, where the courses shall be
diagonally, and except in special cases, when they shall be laid at such
:, with such crown and at such grade as the city engineer may direct.
ı course of blocks shall be uniform in width and depth, and shall be
;ed and selected for the pavers on the sidewalks, and so laid that *all
itudinal joints or end joints shall be close joints and shall be broken by a lap
: least three inches*, and that joints between courses shall not be more
ı one-half inch in width. The blocks shall then be thoroughly rammed
ourses at least three times by a rammer weighing not less than eighty
pounds—no iron of any kind being allowed on its lower face to come in
act with the paving, and until brought to an unyielding bearing, with
ıiform surface, true to the roadway on the established grade. The sur-
of the pavement thus completed must be even and smooth throughout
molded to conform to the wells of the surface sewers, street and alley
rsections, drainage details, and the grade lines established by the city
neer. During the final ramming the pavement shall be tested with a
ight-edge and templet, and any unevenness must be taken out and made
to the required grade, level, and cross-section.

a paving pitch filler is used, the joints shall be filled with clean, dry,
gravel of proper size as herein specified, heated in pans especially pro-
ɪd for that purpose, and poured from cans having small spouts and thor-
ıly settled in place with wire picks until the level of the gravel is at least
inches below the top of the pavement.

he gravel used between the blocks shall be of such size as will pass through
eve having four meshes per square inch, and be retained on a sieve of
y-four meshes per square inch, and must be screened when dry.

here shall be immediately poured into the joints, while the gravel is hot,
ing paving cement as hereinafter described, heated to a temperature of
' F. until the joints and all interstices of gravel filling are full and will
: no more, and are filled flush with the top of the blocks. Dry, hot gravel
ıt then be poured along the joints, filled with paving cement, as above
:ribed.

'he paving cement to be used in filling the joints as herein provided shall
ı paving pitch of the best quality, of a brand that has been proved by
ıal use in pavements known to the city engineer to be best adapted to
purpose. It shall be delivered on the work in lots at least one week
›re using, in order that the necessary analysis and examination may be
le by the city engineer. In addition to this the contractor must furnish
city engineer with the certificate of the manufacturer or refiner that the
ıerials are of the kind specified.

'he city engineer may direct that a Portland cement grout filler may be
l in the joints instead of a paving pitch, in which case the pavement shall
thoroughly sprinkled or washed with water before grouting. The grout
ll be mixed with clean, sharp sand of approved quality, in the proportion
›ne to one, the cement and sand to be thoroughly mixed together dry,
ı box, and then only a sufficient amount of water added to make the grout
:he proper fluidity when thoroughly stirred.

The grout shall be prepared only in small quantities at a time, and shall be stirred rapidly and constantly in the box and while being applied to the pavement, and no settlings or residue will be allowed to be used.

The grout shall be transferred to the pavement in such a way as the engineer may think most advantageous and best for the work, and shall then be rapidly swept into the joints of the pavement with proper brooms. The stones shall be well wet as directed before the grout is applied, and the pouring must be continued until the joints remain full.

All teams and traffic of any kind, except on planks, shall be rigidly prohibited on the pavement for ten days after the grout is applied, or until, in the opinion of the engineer, it has become thoroughly set and hardened, so that the bond will not be broken by traffic over the pavement.

STANDARD SPECIFICATIONS FOR HIGHWAY BRIDGE CONSTRUCTION

Series of 1917

IOWA STATE HIGHWAY COMMISSION

AMES, IOWA

Section Three

GENERAL CONSTRUCTION AND MATERIAL CLAUSES

GENERAL INSTRUCTIONS

1. **Location and Alignment.**—The general location and elevation of the structure at the proposed site will be determined by the engineer, but the contractor shall assume full responsibility for the alignment, elevations and dimensions of each and all parts of the work and their mutual agreement.

2. **Excavation.**—The depth of all foundations shall be shown on the accompanying drawings and the prices bid shall cover the total cost of foundations carried to the elevations shown.

If directed by the engineer, the contractor shall carry the excavation deeper and this cost shall be covered as follows:

For the first two feet or fraction thereof below elevation shown on the plans, the cost of excavation shall be included in the price bid per cubic yard for additional concrete placed below the elevation of bottom of footings. For excavation carried below this depth, *i.e.*, 2 feet below elevation of bottom of footings as shown on plans, the contractor shall be allowed actual cost plus ten per cent., in addition to the unit price bid for extra concret in foundations.

If rock foundation is secured, the excavation shall be done in such a manner as to allow the rock to be exposed and prepared for receiving the concrete. All loose and disintegrated rock or thin strata shall be stripped to a clean bed acceptable to the engineer.

3. **Additional or Less Concrete.**—Additional concrete placed or concrete not placed shall be paid for at the prices stipulated in the form of tender. All costs of excavations are included in the price bid on additional concrete except as noted in Section 3, Paragraph 2.

4. **Inspection of Excavation Forms and Reinforcing.**—After the excavation is completed the contractor shall notify the engineer who shall make an inspection of the depth and character of the foundation. No concrete shall be run or masonry placed until after the engineer has approved the depth and character of foundation material.

After the forms are constructed and the reinforcing secured in place and before any concrete is run the contractor shall notify the engineer who shall make an inspection of the forms and reinforcing.

The county shall be responsible for all delays caused by the failure to make inspection after a twenty-four (24) hour notice has been given by the contractor or his authorized agent.

5. **Filling.**—The contractor shall do no filling work around completed ridges or culverts without the permission of the engineer. If any filling contemplated in this contract it shall be specifically provided for in the roposal. Specifications governing the manner of placing the filling around ridges and culverts will be found under the detailed specifications for that ype of structure.

It shall be the duty of the county engineer to report to the board of superisors the actual cost of filling over or around bridges and culverts on the ownship road system.

6. **Removal of Present Structure.**—Prices bid for each structure shall iclude the cost of removing any existing structure, but it is understood hat the contractor may use during construction any material in such old tructure that is not needed by the county for building a temporary crossing. sable material shall not be cut or otherwise destroyed, and on completion f the work, the contractor shall pile this material in an accessible location s directed by the engineer.

Concrete Masonry

7. **Concrete Measuring and Proportioning.**—The proportions of the differnt classes of concrete shall be carefully secured by some method of measurig satisfactory to the engineer, the cement being measured as packed by the ianufacturers and the aggregate loose. The use of bottomless boxes and quare wheelbarrows of uniform size designed for this purpose, will be acpted as satisfactory methods.

8. **Concrete Mixing and Placing.**—All concrete used under these specificaons shall be thoroughly mixed in a machine mixer of the batch type. The oncrete shall be mixed continuously for a minimum of twelve (12) revoluons in a mixer having an approximate speed of 12 revolutions per minute. he plant shall be equipped and arranged to mix and place the concrete uickly and uniformly. Care shall be taken not to bulge the forms in placing oncrete and all exposed faces shall be worked in some manner to bring a ick layer of mortar in contact with the forms. The consistency of the oncrete shall be such that water will thoroughly flush the surface under mping.

All top surfaces of walls, abutments, girders, floors, copings and handiling shall be carefully tamped and trowelled to a smooth, even surface, id shall be protected while setting from the direct rays of the sun.

Note.—One of the most important factors of good concrete is proper mixing id no deviation from the above requirements will be permitted except by ritten orders of the engineer.

9. **Hydrated Lime.**—Where a dense or impervious concrete is desired e engineer may specify the use of not to exceed eight per cent (8%) (by eight of cement) of hydrated lime. The hydrated lime used shall conform the requirements of the standard specifications of the American Society r Testing Materials.

If hydrated lime is to be used the engineer shall specify in the instructions bidders the portions of the work to which the hydrated lime is to be added.

10. **Concrete in Freezing Weather.**—No concrete shall be laid in freezing eather without the permission of the engineer. For placing concrete iring freezing weather, a suitable plant shall be established by the conactor subject to the approval of the engineer. The water, sand, gravel d crushed stone shall be heated and the concrete masonry protected as rected by the engineer.

11. **Curing Cement.**—Careful attention shall be given by the contractor the proper curing of the concrete. Handrails, floors, and trowelled rfaces shall be protected from the sun, and in dry, hot weather, the whole ucture shall be kept damp for a period of one week. The floors on conete and steel bridges shall be covered with damp sand or other suitable aterial as soon as the concrete has taken its initial set. Other precautions insure thorough curing of the concrete shall be taken by the contractor as ected by the engineer.

MATERIALS

Concrete Materials

12. **Cement.**—The cement shall be a standard Portland Cement of a and approved by the engineer and shall conform to the standard specificans of the American Society for Testing Materials, effective January 1, 17. If car load shipments are made, the engineer shall have at least

ten (10) days after the cement is delivered to the work to make such tests as he may think desirable before it is used. If the cement fails to pass the accelerated test for soundness, it may be held for the 28-day test. Care must be exercised in the storing and protection of the cement on the work and any cement damaged by moisture or which fails to meet any of the above requirements, shall be rejected.

13. **Water.**—Water used in concrete shall be fresh, clean and free from dirt and sewage or alkali and shall be used in such quantities as the engineer directs.

14. **Sand.**—The sand shall consist of clean, siliceous grains uniformly graded in size, from finest particles up to a diameter passing a ¼" screen. shall contain not more than two and one-half per cent. (2½%) of clay by actual dry weight.

NOTE.—If tested with water in a graduate the apparent clay content after one hour settlement shall not exceed seven (7%) per cent.

15. **Screened Gravel.**—Screened gravel shall be uniformly graded in size from grains rejected by a ¼" screen to those passing a 1½" screen for Class "A" and Class "C" concrete, and to those passing a 2½" screen for Class "B" concrete. Any material containing shale, lumps, disintegrated or rotten boulders or clay exceeding two and one-half per cent. (2½%) dry weight, shall be rejected, unless by washing a clean product can be produced.

16. **Unscreened Gravel.**—Unscreened or pit-run gravel shall conform to the above requirements for sand and gravel as to size, cleanness, and quality. The engineer may permit the use of unscreened or pit-run gravel subject to frequent tests to determine the relative proportions of sand and pebbles. If unscreened gravel is used the proportions shall conform strictly to the requirements of each class of concrete specified.

17. **Crushed Stone.**—All crushed stone shall be clean and hard showing a fine compact grain. The quality of crushed stone required will be met by trap, quartzite or limestone, having a French coefficient of wear of not less than 6. Stone dust or dirt appearing as a film covering the individual pieces, will cause rejection unless the stone is cleaned by washing. The crushed stone when delivered at the site shall be placed on planks or other suitable material to prevent its being mixed with dirt or other injurious substances. The crushed stone shall be placed in separate storage piles from the fine aggregate.

Concrete Classes for Screened and Graded Aggregate

18. **Class "A" Concrete.**—1 part cement; 2 parts sand; 4 parts crushed stone or screened pebbles passing 1½" screen.

19. **Class "B" Concrete.**—1 part cement; 2½ parts sand; 5 parts crushed stone or screened pebbles passing a 2½" screen.

20. **Class "C" or Thin Section Concrete.**—1 part cement; 2 parts sand; 3½ parts crushed stone or screened pebbles passing a ¾" screen.

21. **Hand Rail Concrete.**—1 part cement; 2½ parts screened sand; or 1 part cement; 1½ parts sand; 1½ parts crushed quartzite passing a ⅜" screen.

Quantities For One Yard Of Concrete Using Screened Material

22. **Approximate Quantities.**—For ordinary materials, sand screened through a ¼" screen and aggregate of size as specified in the various classes the following are approximate quantities required per cubic yard of concrete:

Kind	Cement	Sand	Broken Stone
Class "A".......	1.46 bbl.	0.44 cu. yd.	0.89 cu. yd.
Class "B".......	1.19 "	0.46 " "	0.91 " "
Class "C".......	1.68 "	0.47 " "	0.83 " "
Hand Rail.......	2.84 "	1.00 " "	

NOTE.—It shall be permissible for the engineer to slightly vary the above proportions of sand and aggregate for the different classes to secure a denser concrete with materials used.

Proportions and Quantities for Unscreened or Pit-run Gravel

23. **Proportion and Quantities for Unscreened Gravel.**—If the engineer permits the use of unscreened or pit-run gravel frequent determination shall be made of the amount of sand passing a 1/8" screen and the concrete shall be proportioned by the following tables for the various classes of concrete as specified:

24. **Class "A" Concrete Pit-run Gravel.**—

CLASS A

Sand Passing 1/8" Screen	Proportions: Cement Pit-run Gravel	No. Barrels Cement per Cu. Yd. of Concrete
42 %	1 sk. to 4.50 cu. ft.	1.50 bbl.
45"	1 " " 4.00 " "	1.68 "
55"	1 " " 3.50 " "	1.90 "
65"	1 " " 3.00 " "	2.25 "

(Not to exceed 65 % sand passing 1/8" screen.)

25. **Class "B" Concrete Pit-run Gravel.**—

CLASS B

Sand Passing 1/8" Screen	Proportions: Cement Pit-run Gravel	No. Barrels Cement per Cu. Yd. of Concrete
42 %	1 sk. to 5.5 cu. ft.	1.22 bbl.
45"	1 " " 5.0 " "	1.35 "
55"	1 " " 4.5 " "	1.50 "
65"	1 " " 4.0 " "	1.68 "

(Not to exceed 65 % sand passing 1/8" screen.)

CLASS C

26. **Class "C" Concrete Pit-run Gravel.**—Same as Class "A" for Unscreened Aggregate.

27. **Hand Stone.**—In piers, abutments and bases of wing and retaining walls with sections two feet thick and over, it will be permissible to use hand stone. If used, the individual pieces shall be carefully placed not less than their own thickness apart nor less than 6" from any face of the concrete.

28. **Mortars.**—All mortars shall be specified by classes, the same letters indicating the same proportion of sand to cement as in the classes of concrete. Par. 18 to Par. 21, Sec. three.

Reinforcement Steel

29. **Reinforcement Steel.**—All reinforcement steel required shall have net sectional areas, distribution and sizes as shown on the plans, and shall have a deformed section to provide a mechanical bond at frequent intervals between steel and concrete. The steel shall meet the requirements of the standard specifications for billet steel concrete reinforcement bars adopted by the American Society for Testing Materials, 1911, revised 1914, with the limitations that all steel shall be made by the open hearth process and all

bars shall be rolled from new billets of the structural steel or hard grade. Any form of bar will be approved for use under the specifications that provides a net section equivalent to the net section of a plain, square bar of the size indicated on the drawing.

All bars shall be free from rust, dirt, paint or grease, and shall present a clean, fresh surface when placed in the structure. Each bar shall be held rigidly to position by blocking to the forms and wiring to the bars at contact points. In general, all reinforcement steel shall be placed securely in position before the concrete is run.

In splicing bars a minimum lap of 24 diameters shall be used.

NOTE.—Shop bent reinforcement shall preferably be used for slab and girder bridges.

30. **Structural Steel in Concrete.**—All structural steel used for concrete reinforcement shall be designed to meet the requirements of Section eight.

Forms

31. **Forms.**—All forms and centerings shall be built of material sufficient in thickness and strength to hold the concrete without bulging between supports. Additional requirements for each particular class of work are specified under that class.

Square corners shall be filleted and for all projections of the concrete the containing forms shall be given a bevel of 1″ per foot. Beveled forms shall be so framed as to increase the thickness of any such projections at their base, and to maintain as the minimum the dimensions shown on the plans.

Piling

32. **Timber Foundation Piling.**—Timber piling used in the foundation shall be cut from sound trees, shall be close-grained and solid and free from defects, such as injurious ring shakes, large, unsound or loose knots and decay, or other defects which will materially impair their strength or durability.

Timber piling for foundations shall be of white, willow, burr or post oak, red cedar, western or white cedar, cypress, chestnut, tamarack, Douglas fir, long leaf southern pine, Norway pine, or any other wood that will satisfactorily resist the blow of the hammer and is durable.

Timber piles must be cut above the ground swell and have a uniform taper. A line drawn from the center of the butt to the center of the tip shall lie within the body of the pile. All knots must be trimmed close to the body of the pile, and all bark removed soon after cutting.

For round piles the minimum diameter at the tip shall be 8″ for all lengths. The minimum butt diameter for any pile shall be 10″. All piling ordered by the engineer shall be in multiples of 2 foot lengths.

Where used the piling shall be designed to carry the full load. To carry the safe load per pile the following formula shall be used:

Safe load in lb. $= \dfrac{2wh}{s+1}$ in which w = weight of hammer in pounds, h = fall in feet and s = average penetration in inches for the last three blows of the hammer.

After driving the piling the tops shall be trimmed of all broomed wood. The minimum projection into the concrete shall be 12″ and the maximum projection 18″.

The price paid for piling shall be paid for the full length of the pile in the leads as ordered by the engineer or shown on the plans, and all piles required shall be ordered, number and length to be specified, within ten days after the contract is signed.

Piling delivered to the site and not driven shall be taken over by the county at cost to the contractor, as shown by the original material and freight bills. This cost shall include the actual cost of the piling delivered to the bridge site plus any actual expense incurred by the contractor in delivering pile driving equipment to the bridge site.

The total lineal feet of piling which is expected to be used with each bridge shall be used in comparing bids received. The right is reserved to make specific conditions for the furnishing and driving of piling for any particular bridge.

The price bid for piling includes driving the piling to place in the foundation and no extras will be allowed above the price bid. The piling shall be driven to a "good refusal" and to the satisfaction of the engineer.

Section Four

TYPES OF BRIDGES AND LOADINGS

CLASSIFICATION

These specifications outline the minimum requirements for ordinary per- ɪnent highway bridges, such as are necessary generally outside the limits the larger cities. One class only, Class A, is recognized throughout with single exception of the Class B loading for wood floors on permanent el bridges.

If any structures are to be built under these specifications to provide for avy city traffic, street car or interurban loadings, the standard loadings set forth herein are not applicable, and special specifications will be sup- ed by the Commission to meet these requirements on application of the ard or engineer.

Bridges erected over drainage ditches shall, where necessary, be so con- ucted as to allow the superstructure to be removed for cleaning said tches with as little damage to the removal and permanent parts of said idge as practicable. The county engineer shall in all cases determine the cessity of making provision for such construction.

Types of Bridges

1. **Steel Bridges.**—These standard specifications have reference to the llowing types of bridges:
Steel I-beams Spans up to 32 ft. in length.
Plate Girder Spans, 20 ft. to 80 ft.
Pony Truss Spans, riveted, 30 ft. to 100 ft.
High Truss Spans, 100 ft. and over, riveted up to 140 ft.

2. **Reinforced Concrete Bridges and Culverts.**—
Box Culverts up to 16 ft. span.
Slab Bridges from 14 ft. to 25 ft. span.
Arch Bridges and Culverts, 6 ft. span and over.
Girder Bridges from 24 ft. to 40 ft. spans.

3. **Other Types of Culverts.**—These specifications do not apply to various pes of small culverts such as circular concrete culverts, vitrified pipe tile, rrugated iron, boiler iron or reinforced concrete pipe. Detailed specifica- ons are prepared for each of these types.

4. **Standard Plans.**—Standard plans of the State Highway Commission re drawn in accordance with these standard specifications and are designed interpret the minimum requirements herein stipulated. These plans will e supplied to all county engineers and special and detailed plans will be upplied by the Commission on request of county engineers and county upervisors without cost to the county.

Loadings

5. **Dead Loadings.**—Plans submitted under these specifications shall pro- ide for the following loadings:
Dead Loadings:
The dead loading includes the weight of structure, floor and filling, using the following unit weights:

Earth filling	120	lb. per cu. ft.
Concrete	150	" " " "
Brick	150	" " " "
Timber—Untreated	3½	" " ft. B. M.
Timber—Treated	5	" " " " "

6. **Loadings for Steel Trusses.**—Uniform Live Load:

Not less than	100	lb. per sq. ft. for spans		up to 50′
" " "	90	" " " " " "	50′	" " 100′
" " "	80	" " " " " "	100′	" " 150′
" " "	70	" " " " " "	150′	" " 200′
" " "	60	" " " " " "	200′	" " 250′

NOTE.—Decrease 0.2 lb. for each increase of 1 ft. in length down to minimum of 50 lb. per sq. ft.
Uniform Live Load for Sidewalks: 50 lb. per sq. ft.

Class "A" Floors and Sidewalks

7. **Loadings for Floors on Steel Bridges.**—Uniform Live Load: 100 lb. per sq. ft.

Concentrated Live Load: For Class "A" floors the minimum concentrated live load shall be a fifteen ton traction engine distributed as follows:

10,000 lb. on front wheels.
20,000 lb. on back wheels.
Distance between front and rear axle, 11′ 0″.
Distance center to center of back wheels, 6′ 0″.
Width of back wheels, 22″.

For concrete floors on steel bridges without joists the above wheel loading is to be distributed 4′ longitudinally and 4′ transversely.

For concrete floors on steel bridges with joists ⅓ of a wheel loading as above is to be distributed to each joist.

The above loadings shall be so placed as to produce maximum stresses in joists and floor beams. Diagrams for distribution of this loading are shown on the standard plans of the Highway Commission for truss spans.

Uniform live load for sidewalks, stringers and brackets 75 lb. per square foot.

Class "B" Floors

Uniform Live Load: 100 lb. per square foot.

Concentrated Live Load: The minimum concentrated live load for Class "B" floors shall be a ten ton traction engine having the distribution of loadings directly proportionate to that specified for the 15 ton engine loading. This loading is to be applied only to the floors of steel bridges and may be used only on the township road system, or for temporary use with wood joists and wood flooring on steel trusses for the county road system. The distribution of each wheel load on the joists shall be 50% to the joist directly under the wheel and 25% to the joists on either side.

8. **Wind Loadings.**—Wind and lateral forces on steel spans shall be assumed as 150 lb. per lineal foot of span on the unloaded chord and 300 lb. per lineal foot of span on the loaded chord, all loads to be considered as moving. For the towers of steel viaducts the wind and lateral forces shall be assumed as follows: 30 lb. per square foot on one and one-half times the vertical projection of the girders, 100 lb. per foot of vertical height of bent, and a load of 100 lb. per lineal foot of span applied 4′ 6″ above grade.

9. **Loadings for Concrete Girders, Slabs and Floors.**—Dead Loading: As specified in Paragraph five.

Uniform Live Load: 100 lb. per square foot of roadway and sidewalk surface.

Concentrated Live Load: Minimum concentrated load consisting of a 15 ton traction engine. For heavy slabs the distribution is to be as follows:

20,000 lb. on rear wheels.
10,000 lb. on front wheels.
11′ 0″ between axles.
6′ 0″ center to center of back wheels.
Width of wheels, 22″.

Each back wheel load is assumed to be distributed 6′ 0″ transversely and 5′ 0″ longitudinally. For thin slabs on girders the same wheel load is assumed to be distributed 4′ 0″ longitudinally and 4′ 0″ transversely.

Typical detail drawings of concrete floors, slabs and girders will be supplied by the Commission to indicate the requirements of these specifications.

10. **Loadings for Concrete Arches.**—Dead Loading: As specified in paragraph 5.

Uniform Live Load: 100 lb. per square foot over roadways and sidewalk surfaces.

Concentrated Live Load: Fifteen ton traction engine so placed as to produce in combination with the dead load stresses maximum stresses in the arch rings.

Allowance for temperature: Concrete arch bridges shall be designed to provide for stresses induced by a temperature range of 80 degrees F.

Contractor's Plans

11. **Contractor's Plans.**—All plans submitted under these specifications shall be in sufficient detail to show amount, kind, sizes and quality of material and type of construction to be used. They shall specify the amount of waterways and depth of foundation below low water.

NOTE.—For all bridges for which plans are prepared by the contractor the engineer shall supply as a basis for the design a profile of the steam crossing, showing foundation soundings, grade line of finished roadway, waterway required, and such other information as necessary to define accurately the structure required.

Section Five

BOX CULVERTS, SLAB AND GIRDER BRIDGES

1. **Standard Plans.**—Standard plans for concrete box culverts, slab and girder bridges will be furnished by the Commission to the county boards and engineers to supplement and interpret requirements of these specifications.

2. **Roadways—County Road System.**—For bridges of the above types ample roadway should be provided. The following table gives the recommended minimum width of roadway for average conditions of traffic, but these widths should be increased inside of corporations or where traffic is unusually heavy. The minimum legal width of roadway is also specified. These widths refer to the minimum width of finished roadway.

Side slopes are to be figured at one vertical to 1½ horizontal in determining the length of culverts and bridges under fills. The width of roadway for each specified structure shall be as specified on the plans.

ROADWAYS FOR COUNTY ROAD SYSTEMS

Type	Span	Recommended Minimum Width of Roadway	Minimum Legal Width of Roadway
Box culverts...........	. 2′ to 16″	24′–0″	20′–0″
Slab bridges...........	16′ to 25″	20′–0″	16′–0″
Girder bridges..........	16′ to 60″	20′–0″	16′–0″

3. **Roadways—Township Road System.**—For roadways of culverts and bridges of above type on township road system, the recommended minimum width is shown in the following table, also the minimum legal width. For roads which are at present included in the township road system but which will later be included in the county road system, and which now carry large traffic, the width of roadways given under the county road system should apply.

ROADWAYS FOR TOWNSHIP ROAD SYSTEMS

Type	Span	Recommended Minimum Width of Roadway	Minimum Legal Width of Roadway
Box culverts...........	2′ to 16″	20′–0″	20′–0″
Slab bridges...........	Over 16′	18′–0″	16′–0″
Girder bridges..........	All spans	18′–0″	16′–0″

4. **Design and Loadings.**—In general the dimensions shown on the standard plans of the Commission are minimum for each size and type of structure. The loadings shall be as specified in Section Four.

5. **Permissible Stresses.**—The stresses used in designing slab and girder bridges shall not exceed the following:

Concrete in compression	600 lb. per sq. in.
Concrete in tension	0 " " " "
Concrete in shear	100 " " " "

(Diagonal tension, reinforced members)

Steel in tension	16,000 lb. per sq. in.
Steel in compression	15 times the surrounding concrete.

6. **Footings.**—Footings shall be carried down below the stream bed a minimum distance of 4 feet to a stiff clay or harder foundation, except for spans under 16 feet which may be built without footings but with a heavily reinforced floor distributing the pressure on the foundation. The floor or footings of slab culverts under heavy fills, shall be designed to distribute the pressure the full length of the foundations by longitudinal reinforcing. The foundation pressure for ordinary soils shall not exceed two (2) tons per square foot.

Depth of footings shown on the standard plans of the Commission should be increased or decreased to reach a firm foundation satisfactory to the engineer. For drainage ditches on very flat grades which will fill, the top of the footings may be made level with the grade line of the ditch. Curtain walls should be used at each end of the floor, and in streams having a swift current or subject to heavy floods the floors should be continued to the end of the wings on the downstream side and a curtain wall placed across the end of this paving.

Compensation for extra depth of footings shall be as specified in Section 3, Paragraph 2.

After the excavation is completed no concrete shall be run in the footings of abutments or piers until the engineer has approved the depth of excavation and the character of the foundation.

7. **Piling.**—If a suitable foundation is not found for the footings 4 feet below the dry weather surface of the stream, piling shall be used, driven 3 feet centers. The top of the piles shall project not less than 12 inches nor more than 18 inches into the concrete after all damaged wood has been cut off. Where piling are used they shall carry the full load.

Safe load on piling shall be figured as specified in Section 3, Paragraph 32.

For all concrete bridges 25-foot span and above for which rock foundation is not available the use of wood piling under the footings is recommended to insure permanency.

8. **Reinforcement.**—The reinforcing steel shall be placed not less than one (1) inch from any outside surface and shall be held in place, as shown in the plans, by blocking from the forms and wiring to other reinforcement at contact points. For the bending required in either slab or girder reinforcement, shop bending is preferable. The contractor shall be held responsible for accurately placing the steel in the position and true to the shape required on the plans. All the reinforcing in slabs and girders shall be placed, spaced and secured in position before the concrete is run. All slabs shall be well reinforced transversely as well as longitudinally. Stirrups shall be used in girder bridges to carry the shear. For material see Section 3, Paragraph 29.

9. **Concrete in Slab Bridges.**—The following classes of concrete shall be used in slab bridges:

Abutments, wingwalls and slabs—Class "A."

Hand rail—hand rail concrete.

Concrete shall be placed in the abutments in uniform layers across the length of each abutment, care being taken to secure a good bond between the footings and the abutment wall. A full longitudinal section of the floor slab shall be run continuously, any unavoidable joints being made in a longitudinal direction.

10. **Concrete in Girder Bridges.**—The following classes of concrete shall be used in girder bridges:

Abutments, wingwalls, girders and floor—Class "A."

Hand rail—hand rail concrete.

Each girder shall be concreted in a continuous operation, the concrete being placed in layers along the length of the girders. The contractor shall provide adequate equipment to insure the completion of each superstructure within ten hours after the first concrete is placed.

11. **Forms.**—Forms for girders and slabs shall be built tight to allow the use of a wet mixture. Water in excess shall not be used. The forms for all exposed faces of the concrete shall be dressed smoothly and evenly.

In general piling shall be driven to support the forms for all girder bridges rigidly in position while the concrete is being poured. If appreciable settlement occurs in the forms, the engineer shall stop the work and require a thorough remodeling to insure without question a completed product true to line and grade as shown on the plans.

To insure a first-class finish, the forms shall be painted with linseed oil or some other means taken to prevent the concrete from adhering to the lumber, and all form lumber used the second time shall be cleaned, and warped or bulged surfaces resized. The sharp angles in the forms shall be filled to prevent thin or sharp corners in the concrete.

12. **Hand Railing.**—The prices bid shall be on the form shown on the plans, but the contractor may submit alternate designs and bids.

13. **Expansion Joints.**—Expansion joints shall be left between the abutments and floor slabs or girders. The details of these expansion joints shall be as shown on the standard plans of the commission for each type.

14. **Name Plate.**—On important bridges the contractor shall furnish and set a name plate of design acceptable to the engineer.

15. **Camber.**—All single span girder and slab bridges shall be given a permanent camber equal to $\frac{1}{20}$ inch per foot of clear span. Bridges of two or more spans shall be given a camber at the center not less than $\frac{1}{20}$ inch per foot of structure.

16. **Finishing and Curing.**—The tops of all accessible surfaces shall be trowelled to a smooth finish using a richer mortar for this purpose if necessary to produce a smooth finish. All fresh concrete shall be protected from the direct rays of the sun, and shall be kept damp for at least one week following placing. The contractor shall follow the directions of the engineer, and shall provide such means as he directs to insure a thoroughly cured product.

17. **Removal of Forms.**—The forms under box culverts 8′ × 8′ and larger slabs, and girders shall remain in place in warm weather not less than three weeks and in cold weather at the discretion of the engineer. On box culverts having a clear span of less than 8 feet the forms shall remain in place for a period of ten days after the concrete in the top slab is poured.

As soon as forms are removed all rough places or holes shall be filled with mortar of the same grade as the concrete used, and if necessary to insure its uniform appearance of smoothness a fresh coat of 1 to 1 mortar shall be applied to the entire outside surface of the structure. This shall be done by the contractor at the direction of the engineer, without extra compensation, as it is the intent of these specifications to provide for material and workmanship that will produce a first-class quality of concrete and a smooth neat appearance, and every precaution shall be taken by the contractor to insure such.

18. **Drainage of Floors.**—Floors on slab and girder bridges shall be drained where necessary by tile drains and the top sloped toward these drains. The drainage from floors shall preferably be carried off through drain pipes in the floors.

19. **Sidewalks.**—Sidewalks where built shall conform to the requirements of the incorporation in which they are built. Dimensions and details shall be shown on the plans.

20. **Filling.**—Unless specifically provided in the contract it is understood that the contractor will do no filling over structures of the above type. The earth fill shall be placed under direction of the engineer, and shall be carried against all walls in horizontal layers avoiding wedge-shaped sections of earth against side walls or wings. The fill shall not exceed the depth specified on the plans, and shall not be placed over box culverts until the concrete has been in place ten days.

For the floor of deck and through girders and slab bridges which carry a light fill, a bituminous floor covering is recommended, as specified in Section 8, Paragraph 82. If used, specific provision shall be made for such floors in the contract.

21. **Wearing Surface.**—All concrete floors on slabs and girders not covered with a bituminous surface shall be finished with a one-half inch (½″) wearing surface of 1 to 1 mortar. Immediately after the concrete floor has been poured to the required thickness and before the concrete has reached its initial set the entire top surface of the floor shall be covered with a 1 to 1 wearing surface of sand and cement. This mortar coat shall be rubbed in and finished with a heavy wood float in such a manner as to provide a smooth even wearing surface.

Section Six

CONCRETE ARCHES

1. **Roadways—County Road System.**—For bridges of the above types ample roadway should be provided. The following table gives the recommended minimum width of roadway for average conditions of traffic, but this width should be increased inside of corporations or where traffic is unusually heavy. The minimum legal width of roadway is also specified. These widths refer to the minimum width of finished roadway.

Side slopes are to be figured at 1 vertical to 1½ horizontal in determining the length of culverts and bridges under fills. The width of roadway for each specified structure shall be as specified on the plans.

ROADWAYS FOR COUNTY ROAD SYSTEMS

Type	Span	Recommended Minimum Width	Minimum Legal Width
Arch culverts.....	Up to 16′	24′–0″	20′–0″
Bridges...........	Above 16′	20′–0″	16′–0″

2. **Roadways—Township Road System.**—For roadways of culverts and bridges of above type on township road system, the recommended minimum width is shown in the following table, also the minimum legal width. For roads which are at present included in the township road system but which will later be included in the county road system, and which now carry large traffic, the width of roadways given under the county road system should apply.

ROADWAYS FOR TOWNSHIP ROAD SYSTEMS

Type	Span	Recommended Minimum Width	Minimum Legal Width
Arch culverts.....	Up to 16′	20′–0″	20′–0″
Bridges...........	Above 16′	18′–0″	16′–0″

In general, specific plans in accordance with these specifications will be furnished for arch designs by the Commission on request of the engineer or board.

3. **Design and Loadings.**—In all designs the dimensions of concrete and areas of steel at each point shall be proportioned to carry the loadings including the temperature stresses as specified in Paragraph 10, Section 4.

4. **Permissible Stresses.**—The materials used shall not be stressed above the following units:

Concrete in compression—600 lb. per sq. in.
Concrete in tension—0 lb. per sq. in.
Steel in tension—16,000 lb. per sq. in.
Steel in compression—15 times surrounding concrete.

For arch rings, with temperature stresses included, the following units may be used:

Concrete in compression—750 lb. per sq. in.
Steel in tension—20,000 lb. per sq. in.

5. **Piling.**—If a suitable foundation is not found for the footings 5 feet below the bed of the stream, piling may be used. The top of the piles shall project not less than 12 inches or more than 18 inches into the concrete after all damaged wood has been cut off.

Piling if used, shall take the full load, spacing to be determined by the formula in Section 3, Paragraph 32. In no case shall the maximum load on any single pile exceed twenty tons.

Foundations on piling shall preferably be enclosed by permanent watertight sheet piling with the tops sawed off about 1 foot below low water.

If the engineer orders sheet piling to be left in place, the contractor shall be compensated at the unit prices bid for sheet piling placed permanently. If sheet piling is to be left in place permanently bids shall be

taken on the estimated number of square feet of such piling required, and settlement made on this basis.

Footings for arch culverts under 16-foot span may be carried down to solid foundation or may be reinforced slab floor with curtain walls at one or both ends. Abutments for arch bridge over 16-foot span shall be carried down a minimum depth of 4 feet below bed of stream at its lowest point. Piers shall be carried a minimum depth of 6 feet below the bed of the stream.

6. **Abutments and Footings.**—Allowable pressure under piers and abutments shall not exceed the following units:

Clay, sandy clay—2 tons per sq. ft.
Sand or gravel, confined—2 tons per sq. ft.
Cemented gravel—5 tons per sq. ft.
Rock cleaned to solid bed—up to 25 tons per sq. ft.

The floors of arch culverts shall be protected by curtain walls at either end and in streams having a swift current, or subject to heavy floods, the paving shall be carried to the end of the wing walls at the downstream side and protected with a curtain wall at the extreme end.

Extra depth of excavation shall be paid for as specified in Section 3, Paragraph 2. After the excavation is completed no concrete shall be run in the footings of abutments or piers until the engineer has approved the depth of excavation and the character of the foundation.

7. **Concrete in Arch Bridges.**—The following classes of concrete shall be used in arch bridges:

For arch ring—Class "A" concrete.
For spandrel walls—Class "A" concrete.
For abutments and piers below springing—Class "A" concrete.
For hand rails including all concrete placed above spandrels—hand rail concrete.

Hand stone may be used in abutments, piers and gravity sections.

8. **Steel Reinforcement.**—Steel reinforcement shall be of the quality required in Section 3, Paragraph 29, and shall conform to the detailed requirements of the plans as to size, net areas, bending and position.

Each rod shall be placed and secured in position before the concrete is run. Preferably small concrete blocks shall be used under the steel to block from forms. The concrete covering shall not be less than 1 inch. The area of metal at the crown shall not be less than $\frac{3}{8}$ of 1%.

Arch reinforcement shall be of the double and preferably of the symmetrical type and there shall be at each point in the arch ring a sufficient area of steel to take all the tension, on the assumption that the concrete takes no tension.

9. **Forms.**—Forms for arch bridges shall be built tight and surfaces of all exposed faces dressed smoothly and evenly. Some adequate means shall be taken to insure non-adhesion of the concrete. Lumber used the second time shall be cleaned and resized, if necessary, to insure plane surfaces. Square corners shall be filled.

The contractor shall obtain the approval of the Commission on his centering plans before the work is started.

10. **Removal of Forms.**—The forms under arches shall be left in place a minimum of three weeks in warm weather and in cold weather for a length of time as directed by the engineer. The hand rail shall be built after the forms have been lowered sufficiently to allow the arch ring to take the dead load.

11. **Expansion Joints.**—Expansion joints shall be left in the spandrels and hand rail including the base. The minimum number of expansion joints for spandrels shall be three (3) for arches under 50 ft. span and five (5) for arches above 50 ft. in span. Unless otherwise provided, these shall consist of tongue and groove joints thoroughly waterproofed.

12. **Drainage and Waterproofing.**—The top of the arch ring and lower six inches of the inside surface of the spandrel walls shall be brought to a reasonably smooth surface with a coating of rich cement mortar, then thoroughly covered with a neat cement grout or hot bituminous coating. The method and materials shall be subject to the approval of the engineer. Drainage shall be provided for the back of the arch at each pier and abutment by pipe drains.

13. **Paving and Aprons.**—Paving if used in the bed of the stream, shall be not less than nine (9) inches in thickness and the bottom shall be at least two (2) feet below the bed of the stream. Nine (9) inch aprons shall extend two (2) feet below the top of pavement on both upper and lower sides.

14. **Hand Rail.**—The prices bid shall be of the form and dimensions shown on the plans submitted but the contractor may submit alternate bids and designs.

15. **Name Plate.**—For the large bridges a name plate of design approved by the engineer shall be furnished and set by the contractor.

16. **Sidewalks and Lighting.**—Sidewalks where built shall conform to the requirements of the incorporation in which they are built. Dimensions and details shall be shown on the plans. Details of lighting and wiring shall be clearly specified on the plans and in the instructions to bidders.

17. **Filling.**—Unless otherwise specified in the contract, the board will do the filling. Care should be taken not to fill against green concrete and to load the arch or arches at each end simultaneously. The filling shall be done in horizontal layers, avoiding wedge shaped sections of loose earth or other material against spandrels, wings, and abutments.

Section Seven

SUBSTRUCTURES AND FOUNDATIONS

CONCRETE PIERS AND ABUTMENTS

Standard plans will be furnished by the Commission showing in detail the minimum requirements of the various types of abutments here specified.

1. **Standard Plans and Design.**—The design may be of either the reinforced cantilever, counterforted or gravity section capable of resisting the over-turning action of the earth and the impact of ice jams or floating débris. In either design steel shall be used at all points where tension may be developed. Full dimensions and details shall be shown on accompanying drawings. The clearance shall be at least 2 inches between the parapet wall and the edge of the shoes or bearing plates.

2. **Special Designs.**—Special designs or those calling for the use of steel piling, pedestals, or other constructions not included in the above types or not approved under these specifications will be approved by the Commission only for special cases for which the detailed plans are submitted.

3. **Permissible Stresses.**—Steel in tension—16,000 lb. per sq. in.

Concrete in compression—500 lb. per sq. ft.

Bearing on masonry bridge seats—400 lb. per sq in.

4. **Piling.**—Where foundations acceptable to the board and engineer can not be obtained 4 feet below the bed of the stream, piling may be used. The number and spacing of the piling shall be determined by the formula in Section 3, Paragraph 32. In general the spacing shall not exceed 3′ 0″ center to center. If piling can be driven, its use is recommended under all important structures.

After driving the tops shall be trimmed of all broomed wood. The minimum projection into the concrete shall be 12 inches but the tops of the piling may be left at varying elevations from 12 to 18 inches.

5. **Footings.**—The footings shall extend a minimum distance of 4 feet below the bed of the stream and shall be carried to a firm foundation or placed on piling.

For excavation carried below the elevations as shown on the plans the contractor shall be compensated as provided in Section 3, Paragraph 2.

Before any concrete is placed in footings of piers or abutments, the engineer shall approve the depth of excavation and character of foundations.

6. **Reinforcement.**—In cantilevered, counterforted or other reinforced abutments, the reinforcement shall be placed and secured in position before the concrete is run. Care shall be taken to secure thoroughly ends of all rods as shown on plans.

All reinforcement steel used shall conform to the requirements of Section 3, Paragraph 29.

7. **Concrete in Reinforced Abutments and Wing Walls.**—For reinforced abutments and wings, Class "A" concrete shall be used throughout. The concrete shall be carried up in horizontal layers full length of abutments and wings.

8. **Concrete in Gravity Abutments and Piers.**—For gravity sections the following classes shall be used:

Body of piers and abutments—Class "B."

Coping—Class "A."

Hand stone may be used and concrete must be carried up in horizontal layers.

9. **Joints.**—If the forms are not entirely filled before the cement sets and there are no reinforcing rods projecting, hand stone shall be one-half imbedded to form a bond for the new concrete. The stones shall be carefully placed with their beds parallel to flow of stream.

10. **Cofferdam.**—Pumping will not be permitted from the inside of foundation forms while concrete is being placed, and if necessary to prevent flooding, a seal of concrete shall be placed through a closed chute and allowed to set. Concrete shall not be placed in running water and shall only be placed in still water with suitable appliances and under the direction of the engineer.

The inside dimensions of the cofferdam shall be sufficiently large to give easy access to all parts of the foundation forms. For underwater work a suitable cofferdam shall be provided.

11. **Forms.**—Forms for all exposed faces shall be preferably of T & G lumber, sized and carefully fitted by competent workmen.

Thickness of lumber, spacing of studding, bolting, wiring and external braces shall be sufficiently strong to produce plane surfaces on all exposed faces and to protect green concrete from the sudden rising of the stream.

12. **Pier Anchorage.**—Where rock foundations are secured for piers the footings shall be carried not less than 6 inches into solid rock to secure anchorage or anchor rods not less than 2 inches in diameter and 6 feet long shall be set as shown on accompanying plans.

13. **Ice Breaker.**—On piers built in streams carrying heavy ice, an ice breaker with not less than an 8″ × 8″ × ½″ angle or a Tee rail embedded for cutting edge, shall be provided.

14. **Protection Railing.**—The contractor for the sub-structure shall furnish and install the 2-inch gas pipe protection railing placed on the wings of abutments for steel truss bridges.

15. **Drainage.**—Adequate drainage for the backs of abutments and wings shall be provided by tile or pipe drains through the face of the abutments at the ground line.

16. **Setting Bed Plates.**—Bed plates shall be accurately set to position and elevation in Class "A" mortar, which shall be allowed not less than forty-eight hours in which to harden.

17. **Placing of Superstructure.**—The weight of the superstructure shall not be placed on concrete piers or abutments until, within the judgment of the engineer, the concrete shall be sufficiently set to receive the superstructure without injury to the concrete.

18. **Filling.**—Unless otherwise provided in the contract, all of the filling back of abutments shall be done by the board. The concrete shall be allowed reasonable time to set and the fill shall be carried up in horizontal layers, well tamped. The slope of the old surface back of the abutments shall be destroyed by steppings. All possible care shall be taken to prevent a saturated wedge of the earth fill settling against abutments or wings.

19. **Special Designs and Details.**—Special designs and details shall be clearly shown on general and detailed drawings. The depth and kind of foundations shall be specified.

Tubular Steel Piers

20. **Tubular Steel Piers.**—The minimum diameter of steel tubes used for piers shall be 30 inches and minimum thickness of material shall be ¼ inch. Each pair of tubes shall be rigidly connected by a web extending from the top to within two feet of low water and braced by pairs of angles, at the top and bottom of the web and intermediate splices.

Tubular piers shall not be used for abutments, and shall not be used in any case without consent and approval of the engineer.

Class "B" concrete shall be used for filling. The size, weight, depth of foundation and number of piling must be shown on the drawings.

Section Eight

STEEL SUPERSTRUCTURES

General Design

1. **Types and Loadings.**—The types of bridges and loadings shall be as specified in Section 4.

2. **Dimensions.**—In these specifications, the following dimensions obtain: Span of Girders, distance center to center of bearings.

Span of Trusses, distance center to center of pedestals, or end pins.
Span of Floor Beams, distance center to center of girders or trusses.
Span of Joists, distance center to center of floor beams (one panel length.)
Depth of Girders, distance between centers of gravity of flanges.
Depth of Trusses, distance between center of gravity of chords or between pin centers.

3. **Masonry Layout.**—The masonry layout shall be provided by the contractor for the superstructure within fifteen days after the contract becomes effective. This shall be in sufficient detail to show the position and elevation of all bed plates and anchor bolts.

4. **Clearance.**—On a straight line, the clear height of through bridges shall not be less than 15 feet above the floor for a distance of 3½ feet on each side of center line of roadway. The clear width between trusses for a height of 10 feet above the floor shall be not less than the nominal roadway which in no case is to be less than 16 feet.

5. **Permissible Stresses in Metal.**—All parts of the structure shall be so proportioned that the sum of the maximum stress shall not exceed the following amounts in pounds per square inch except as modified in Paragraphs 8 to 11.

For Steel

Axial tension on net section—16,000.

Axial compression on gross section—$16{,}000 - 70\frac{l}{r}$

Where "l" is the unsupported length of the member in inches and "r" is the least radius of gyration in inches.

Bending: on extreme fibers of rolled shapes, built sections and girders; net sections—16,000.

On extreme fibers of pins, rivets and bolts—25,000.
Shearing: on pins and shop driven rivets—12,000.
On field driven rivets and turned bolts—9,000.
On plate girder web; gross section—10,000.
Bearing on pins and shop driven rivets—24,000.
On field driven rivets and turned bolts—18,000.
On masonry—400.
On expansion rollers or rockers where "d" is the diameter of the rocker or roller in inches, per linear inch—600d.
On pin bearing on rockers—12,000.

For Cast Steel

Tension—16,000.
Compression—16,000.
Shear—10,000.

For Concrete

6. **Permissible Stresses in Concrete.**—Compression—600.
Tension—0.

For Douglas Fir, White Oak and Long Leaf Yellow Pine Timber

7. **Permissible Stresses in Timber.**—Bending extreme fiber—1500.
Tension with grain—1500.
Compression with grain—1500.
Shearing across grain—600.
Shearing along grain stresses—200.

8. **Alternate Stresses.**—Members subject to alternate stress of tension and compression shall be proportioned for the stress giving the largest section. If the alternate stresses occur in succession during the passage of one load, each stress shall be increased by fifty per cent. (50%) of the other. The connections shall in all cases be proportioned for the sum of the stresses.

9. **Counter Stresses.**—Wherever live and dead load stresses are of opposite character, only 70 per cent. of the dead load stress shall be considered as effective in counteracting the live load stress.

10. **Axial and Bending Stresses Combined.**—Members subject to both axial and bending stresses shall be proportioned so that the combined fiber stresses will not exceed the allowed axial stress.

11. **Lateral and Other Stresses Combined.**—For stresses produced by lateral or wind forces combined with those from live and dead load forces, the unit stress may be increased 30 per cent. over those given above; but the section shall not be less than required if the lateral or wind forces be neglected.

12. **Tension Members.**—Net sections must be used in all cases in calculating tension members, deducting the area of rivet holes one-eighth inch (1/8″) in diameter larger than the nominal size of rivet. The net sections at pin holes shall be twenty-five per cent. (25 %) in excess of the net section through the body of the main member. The net section back of the pin hole, parallel to the axis of the member shall be not less than that through the body of the main member. Main tension members shall be composed of sections symmetrically placed about the central plane through the truss.

13. **Limiting Length of Compression Members.**—The length of main compression members shall not exceed 125 times their least radius of gyration.

14. **Proportioning Plate Girders.**—Plate girders shall be proportioned either by the moment of inertia of their net section or by assuming that the flanges are concentrated at their centers of gravity; in which case one-eighth of the gross section of the web, if properly spliced, may be used as flange area.

15. **Compression Flange.**—The gross section of the compression flanges of plate girders shall not be less than the gross section of the tension flange and the unsupported length of the compression flange shall not be greater than 15 times its width.

16. **Depth Ratios.**—Trusses shall preferably have a depth of not less than one-tenth of the span and plate girders a depth of not less than one-twelfth of the span. If shallower trusses or girders are used, the section shall be increased so that the maximum deflection will not be greater than if the above limiting ratios had not been exceeded.

DETAILS OF DESIGN

General Requirements

17. **Open Section and Water Pockets.**—Structures shall be so designed that all parts will be accessible for inspection, cleaning and painting. Any pockets or depression likely to hold water shall be provided with drains or be filled with water-proof material.

18. **Symmetrical Sections.**—Unsymmetrical sections, such as top chords and end posts composed of two rolled or built up channels and a cover plate, shall be proportioned to bring the center of gravity as near as possible to the center of the web.

The neutral axis of the main members around the joints shall intersect at a common point.

19. **Splices.**—All joints in riveted work, whether the stress be tension or compression, shall be spliced to develop the full stress in the members.

20. **Minimum Thickness.**—No material shall be used less than one-quarter inch (1/4″) in thickness except for lining or filling vacant spaces and in webs of rolled channels.

21. **Pitch of Rivets.**—The minimum pitch shall be not less than three diameters of the rivet and perferably not less than the following:

For 7/8 in. rivets, minimum pitch—3 in.
" 3/4 " " " " —2 1/2 in.
" 5/8 " " " " —2 1/4 in.
" 1/2 " " " " —1 3/4 in.

The pitch of rivets in the direction of the strain shall not exceed six inches (6″) or sixteen times the thinnest outside plate. For angles with two gage lines and rivets staggered the maximum shall be 9 inches in each line.

22. **Edge Distance.**—The minimum distance from the center of any rivet hole to a sheared edge shall be:

1 1/2 in. for 7/8 in. rivets.
1 1/4 " " 3/4 " "
1 1/8 " " 5/8 " "
1 " " 1/2 " "

For rolled edges, except flanges of I-beams and channels:

1 1/4 in. for 7/8 in. rivets.
1 1/8 " " 3/4 " "
1 " " 5/8 " "
7/8 " " 1/2 " "

The maximum distance from any edge shall be eight times the thickness of the outside plate, but shall not exceed five inches (5″).

23. **Compression Members.**—In compression members the metal shall be concentrated as much as possible in the webs and flanges. Cover plates shall have a thickness of not less than one-fortieth of the distance between rivet lines.

24. **Tie Plates.**—The open sides of compression members shall be latticed and shall have tie plates at the ends and at intermediate points where the lattice is interrupted. These plates shall have a length equal to the width of the main members on the connected side and a thickness not less than one-fiftieth ($1/50$) of the distance between the rivets connecting them to the member. The minimum thickness shall be one-fourth inch ($1/4''$).

25. **Lattice Bars.**—The minimum width of lattice bars shall be as follows.

$2\frac{1}{2}$ inches for $\frac{7}{8}''$ rivets.
$2\frac{1}{4}$ " " $\frac{3}{4}''$ "
2 " " $\frac{5}{8}''$ "
$1\frac{3}{4}$ " " $\frac{1}{2}''$ "

Single lattice bars shall have an inclination of approximately 60 degrees with the axis of the main member and shall have a minimum thickness of one-fortieth ($1/40$) of the distance between rivets connecting them to the member. When the distance between rivet lines exceeds fifteen inches (15") double lattice bars with an inclination of approximately 45 degrees shall be used. The minimum thickness shall be one-sixtieth ($1/60$) of the distance between the rivets connecting them to the member and they shall be riveted at the intersections.

26. **Pin Plates.**—All pin holes shall be reinforced by plates if necessary These reinforcing plates shall contain sufficient rivets to transfer the proportion of pressure which comes upon them and at least one plate on each side of the member shall extend not less than six inches (6") beyond the tie plate.

27. **Pins.**—Pins shall be long enough to insure a full bearing of all parts connected upon the turned body of the pin. They shall be secured by chambered nuts. The screw ends shall be long enough to admit of burring the threads.

28. **Pin Packing.**—Members shall be symmetrically packed on pins using filler rings if necessary to prevent any lateral movement.

29. **Provision for Temperature Changes.**—Provision for the free expansion and contraction to the extent of one-eighth of an inch for each 10 ft. of length shall be made for all bridges. Spans of 65 feet and less shall have one end free to move on planed surfaces. Above these length, all steel bridges shall be provided with rocker shoes of approved design.

30. **Shoes, Bed Plates and Anchor Bolts.**—Spans over 65 feet in length shall have pin bearing shoes. Details of shoes shall conform to the standard details shown on plans of the Commission.

Cast bed plates shall be planed on top, the cut of the tool paralleling the direction of expansion. All bed plates shall be grouted true to position.

The setting of all anchor bolts for the steel work shall be included as part of the contract for the superstructure. Unless otherwise specified, the bolts shall have a minimum diameter of one and one-fourth inches ($1\frac{1}{4}''$) and shall extend eighteen inches (18") into the masonry and be set in neat Portland cement mortar.

31. **Field Connections.**—The field connections of spans under 70 feet in length may be bolted or riveted at the discretion of the engineer. If field connections for spans of this length are to be riveted, this fact must be specifically stated in the Instructions to Bidders or Form of Tender. The holes in floorbeam connections and joist connections (where the joist connects directly to the web of the floorbeams) must, if bolted, be sub-punched and reamed to iron templates and the open holes in the main splices of trusses must be sub-punched and reamed to size at the shop while the trusses are assembled. The bolts used shall have hex heads and hex nuts and $\frac{1}{4}$ inch washers, and must fit the holes tightly. The bolts shall be threaded to such a length that the thread will end inside the washer and not extend into the effective grip of the bolt. The use of square-headed or button-headed bolts, or square-nuts will not be allowed.

All field connections of all spans 70 feet or more in length erected on permanent abutments shall be riveted except handrail connections as noted below. Handrail connections shall in all cases be bolted.

Floor Systems

32. **Floor Beams.**—Floor beams shall be arranged perpendicularly to the girder or truss at the panel points and in through bridges, shall be riveted to the verticals. Rolled shapes such as floor beams and joists shall be proportioned by their moments of inertia.

33. **Joists.**—Steel joists shall preferably be riveted to the webs of floor beams. Rolled beams used as joists shall be spaced not to exceed 2′ 6″ centers under wood floors.

34. **Beam Bridges.**—Rolled shapes for beam bridges shall be spaced and proportioned as previously specified. The separate lines shall be held truly to position by struts or spreaders. The two outside lines at least shall be rigidly connected by angle or channel struts at intervals of about 8 feet.

NOTE.—In all concrete floor construction over steel shapes, plates or corrugated arches shall not be used over or between the joists or beams.

Bracing

35. **Rigid Bracing.**—All lateral, longitudinal and transverse bracing shall be composed of rigid members.

36. **Through Truss Spans.**—Through truss spans shall have riveted portals rigidly connected to the top chord and end posts. They shall be as deep as the clearance will allow.

Transverse struts shall be provided at all intermediate posts.

The struts in the top lateral system shall be as deep as the chord section and shall be riveted to each flange of the top chord. The section shall preferably be of four angles connected by latticing.

37. **Pony Trusses.**—The top chord of pony trusses shall be securely held to position at the panel points by gusset plates, knee braces or wide-webbed, vertical posts rigidly connected to the floor beams.

38. **Deck Truss.**—Deck truss spans shall be provided with sway bearing at each panel point, sufficient to resist all lateral stresses. Such braces to have riveted connection with the main members.

39. **Steel Trestles.**—Each trestle bent shall be composed of two columns braced together. The majority of bents shall be united in pairs forming a tower which shall be rigidly braced on the four sides and shall have longitudinal and transverse struts at the bases.

Plate Girders

40. **Top Flange**—Through plate girders shall preferably have their upper corners neatly rounded and if flange plates are used one plate of the upper flange shall extend over the corners to the bottom of the girder.

41. **Web Splices.**—The web plates of girders shall be spliced at all joints by a plate on each side, capable of transmitting the full stress through splice rivets. At least two rows of rivets on each side of splice must be used.

42. **Stiffener Angles.**—Stiffener angles shall be placed at points of bearing, at points of concentrated loading and at points required by the formula:

$$d = \frac{t}{40}(12{,}000 - s)$$

Where d = the clear distance between stiffeners or flange angles; t = the thickness of web; s = the shear per square inch on the web.

The stiffeners at ends and at points of concentrated loads shall be determined by the formula:

$$p = 16{,}000 - 70\frac{L}{r}$$

In which p = the allowable unit stress; L = ½ the depth of the girder in inches; r = the radius of gyration of angles neglecting fillers and web.

Trusses

43. **Working Lines.**—In general the following working lines shall be used:

For channels with cover plates used for top chords and end posts, working lines shall be taken as near as practicable to the center of gravity of the section. For two angle chord and diagonal sections the working line may be taken as gage line nearest the back of the angle. For symmetrical sections the working line shall be taken at center of gravity of the section.

44. **Camber.**—All truss spans shall be given a proper camber by increasing the length of the top chords. For spans carrying wood floors, an increase of one-eighth inch (⅛″) for each ten feet of length and for spans carrying con-

crete floors, an increase of three-sixteenths inches (3/16") for each ten feet of length shall be used.

45. **Rigid Members.**—Hip verticals and the two end panels of the bottom chord in pin connected trusses shall be rigid members.

46. **Eye-Bars.**—Eye-bars shall be placed as nearly parallel to the central plane of the truss as possible, the maximum inclination of any bar being one inch (1") in sixteen feet. Adjustable eye-bars used as counters shall have the screw ends upset.

Workmanship

47. **Punching.**—All rivet work must be punched accurately with holes one-sixteenth inch (1/16") larger than the size of rivet used and when the pieces forming one member are put together, the holes must be truly opposite. No drifting to distort metal will be allowed. If necessary to admit the rivets, the holes shall be enlarged by reaming.

48. **Rivets.**—Rivet heads must be of approved hemispherical shape and of uniform size for the same size of rivet throughout the work. They must be full, neatly finished and concentric with the rivet hole. All rivets shall preferably be machine driven by direct acting machines.

49. **Eye-Bars.**—The heads of eye-bars shall be not less in strength than the body of the bar and shall be of an approved make. The head shall be made by upsetting, rolling or forging into shape. Welding in the body of the bar shall not be allowed.

50. **Boring Eye-Bars.**—Eye-bars which are to be placed side by side in the structure shall be bored at the same temperature and at one operation. They shall be of such equal length that upon being piled, the pins shall pass through the holes at both ends simultaneously without driving.

51. **Annealing.**—All eye-bars must be annealed.

52. **Play in Pin Holes.**—The clearance between any pin and pin hole shall be 1/50 of an inch up to four inches (4") in diameter and for pins above four inches (4") not more than 1/32 of an inch.

53. **Pins.**—Pins shall be accurately turned to gages and shall be straight and smooth and entirely free from flaws.

54. **Driving and Pilot Nuts.**—All pins shall be supplied with steel driving and pilot nuts for use during erection.

Structural Material

55. **Grades of Material.**—The superstructure shall be fabricated from the following materials:

Rivet steel, structural steel, cast iron, or cast steel.

56. **Manufacture.**—All steel and steel castings shall conform in detail to the standard specifications of the American Society for Testing Materials, for Strucutral Steel for Bridges, adopted August 16, 1909.

57. **Structural Steel.**—Structural steel shall be used in all parts of the structure except for rivets, shoes, rockers or pedestals.

58. **Rivet Steel.**—All rivets shall be made of rivet steel.

59. **Cast Steel and Cast Iron.**—Shoes, rockers and pedestals shall be made of either cast steel or cast iron. If of cast iron, test bars one inch square, loaded in middle between supports of twelve inches (12") apart shall bear 2500 pounds or over and deflect 0.15 of an inch before rupture.

60. **Name Plate.**—A suitable name plate inscribed as directed by the engineer shall be provided and securely attached.

61. **Hand Rail.**—A steel hand rail of the design shown on the plans shall be provided and accurately lined to position. If material other than steel is desired, the plans shall show the material and construction in detail.

62. **Shop Drawings.**—The contractor shall furnish the engineer two sets of shop drawings. These drawings shall in general be checked by the Commission, and three corrected sets of shop drawings shall be furnished the engineer, one set for his use, one set to be forwarded to the Commission, and one set to be filed as a part of the contract with the county auditor.

Test and Inspection

63. **Tests and Inspection.**—The purchaser under these specifications shall be furnished by the manufacturer with every facility for complete inspection and test and shall on request be supplied with copies of the full orders, shipping invoices and weights.

SPECIFICATIONS FOR PAINT

64. **Metal Must be Clean Before Shop Coat is Put On.**—One shop or prime coat and one field coat of paint shall be applied in conformity with the following requirements.

All metal work (including railings) shall be cleaned from all rust, scale, dirt or grease before the shop coat of paint is applied. If rust, which in the opinion of the inspector can not be removed is found on any piece, that piece shall be rejected. All parts which come in contact shall be painted before they are riveted together. After assembling and riveting, the metal work thoroughly clean and dry, and before leaving the shop, shall be painted carefully with one coat of one of the hereinafter specified prime coat paints. Parts not accessible after erection shall be painted two coats. While metal work is being erected in place all abrasions of the original paint and all rivet and bolt heads and location marks must be cleaned and painted, preparatory to the second coat.

65. **Protecting Machined Surfaces.**—Machined surfaces shall be coated with white lead and tallow before shipment or before being placed in the open.

66. **Paint for Shop Coat.**—The pigment of the paint to be used as the shop or prime coat shall be one of the following according to the final tint or color required by the engineer:

1. Pure Red Lead.
2. Pure Sublimed Blue Lead.
3. Pure Sublimated Sulfate of Lead.
4. Basic Lead or Zinc Chromate.
5. Pure Iron Oxide mixed with not less than 10% Basic Lead or Zinc Chromate.
6. Pure Natural Graphite mixed with not less than 20% Basic Lead or Zinc Chromate.

The word "pure" in the above shall be interpreted as meaning without the addition of any substances foreign to the various pigments such as silica, silicates, and other inert materials or impurities.

No shop painting shall be done in wet or freezing weather unless such painting is done under cover where the conditions are such that no moisture will condense on the surface of the steel and where the temperature of the atmosphere will be above 45 degrees for at least 10 hours per day.

67. **One Coat of Field Paint After Erection.**—After the structure is complete in place, touched up as described above and cleaned of dirt, grease, or oil that may have accumulated during erection, one coat of one of the hereinafter specified field coat paints shall be applied to all accessible parts.

No field painting shall be done in wet weather or when the temperature of the atmosphere is not above 45 degrees F. for at least 10 hours per day.

68. **Paints for Field Coat.**—The paints for field coats shall contain any of the following pigments:

1. Red Lead.
2. Sublimed Blue Lead.
3. Sublimed Sulfate of Lead.
4. Iron Oxide.
5. Pure Graphite (natural).
6. Pure Carbon.

Pigments other than graphite or carbon may contain not more than 25% of inert material such as silica, china clay, or asbestine.

Lampblack, Prussian Blue and Chrome Yellow shall be used for obtaining the proper tints.

The pigment of graphite or carbon paints shall not contain less than 70% total graphitic carbon or carbon.

No paint pigment shall contain more than 5% of either Calcium Carbonate or Calcium Sulfate.

No red lead paint shall be used as a field coat without the addition of some tinting pigment in sufficient quantity to eliminate the fading effect of a straight red lead paint.

69. **Paint Vehicle.**—The paint vehicle in every case shall be pure boiled linseed oil or China wood oil with the necessary amount of Japan dryer to produce a good drying coefficient and shall in no case contain moisture to exceed 0.5%. The amount of volatile vehicle shall not exceed 10% of the vehicle.

A paint containing coal tar or asphaltic products shall not be used.

70. **Percentage of Pigment in Shop Coat.**—The percentage of pigment in the different shop or prime coat paints shall approximate the following:
Red Lead Paints—not less than 65%.
Sublimed Blue Lead Paints—not less than 60%.
Sublimed Lead Sulfate—not less than 60%.
Basic Lead and Zinc Chromate Paint—not less than 60%.
Iron Oxide Paints—not less than 55%.
Graphite Paints—not less than 35%.

71. **Percentage of Pigment in Field Coat.**—The percentage of pigments in the various field coat paints shall approximate the following:
Red Lead Paints—not less than 55%.
Sublimed Blue Lead Paints—not less than 50%.
Sublimed Lead Sulfate Paints—not less than 55%.
Iron Oxide—not less than 50%.
Pure Graphite—not less than 25%.
Pure Carbon—not less than 25%.

The Red Lead of any pigment shall not contain more than 10% of Litharge (PbO) nor more than 1.0% of materials other than Oxide or Carbonate of Lead.

The Sublimed Blue Lead of any pigment shall be a mixture of Lead Sulfate, Sulfite and Sulfid and Lead Oxide and Zinc Oxide and shall contain not less than 30% of uncombined Lead Oxide (PbO).

The Sublimed Lead Sulfate of any pigment shall be a mixture of Lead Sulfate, Basic Lead Carbonate, or Lead Oxide and Zinc Oxide and shall not contain less than 15% of uncombined Lead Oxide (PbO) or the equivalent of Basic Lead Carbonate.

72. **Samples for Testing.**—Before ordering the paint, a sample of at least one quart shall be furnished the engineer, which sample, if approved, will be used in determining the merits of the paint furnished on the work. All paint used must equal the sample in quality.

Samples of the paint delivered at the shop and in the field shall be furnished the engineer by the contractor. These samples shall be tested at the laboratory of the Iowa Highway Commission before any paint is applied.

73. **Manufacturers' Guarantee.**—The contractor should therefore secure the necessary paint in ample time so that no delay to the work will be caused by the time necessarily used in testing for which ten days should be allowed from the time the sample is collected by the inspector.

In order to facilitate contracting and prevent the necessary delays in collecting and testing samples, the contractor may submit to the Highway Commission a certificate of guarantee from the paint manufacturer stating that the paint which said manufacturer intends to supply for a particular job has been tested and accepted by the Highway Commission and that the paint to be furnished is guaranteed to conform in every respect to the sample submitted to the Highway Commission for testing. The following form shall be used by the paint manufacturers:

74. **Form of Guarantee.**—
We do hereby represent and guarantee that the....................
paint which we have furnished....................................
for painting..or other steel structures conforms in every respect to the sample submitted to the Iowa State Highway Commission for the purpose of testing and accepted by them under Laboratory No............

(Signed)...............................

NOTE.—The attention of manufacturers is directed to the requirements of Chapters 11A and 11B, Title 12, Supplement to the Code, 1913, relative to the manufacture and sale of paint and linseed oil.

Floors

75. **Floors.**—The floors shall be included as a part of the contract price of the superstructure.

76. **Timber Floors.**—*Timber floors* shall consist of one thickness of three inch (3") northern fir, yellow pine or white oak laid at right angles to the length of the bridge. The timber used shall be sawed true, of even thickness and free from all defects impairing its strength or durability. Connections, wheel guards and nailing places shall be as shown on the detailed plans.

77. **Concrete Floors.**—*Concrete floors* shall be built of Class "C" concrete. The thickness of concrete, sizes and placing of reinforcing steel shall conform to the detailed drawings. No concrete shall be run until the reinforcing steel has been placed, spaced and secured in position.

78. **Wearing Surface.**—All concrete floors not covered with a bituminous surface shall be finished with a one-half inch (½") wearing surface of 1 to 1 mortar. Immediately after the concrete floor has been poured to the required thickness and before the concrete has reached its initial set the entire top surface of the floor shall be covered with a 1 to 1 wearing surface of sand and cement. This mortar coat shall be rubbed in and finished with a heavy wood float in such a manner as to provide a smooth, even wearing surface.

79. **Expansion Joints.**—Concreting over each span shall be completed in a continuous operation. Expansion shall be provided between spans, and under each end of floors, resting on the abutments. These joints shall be filled with tar or asphalt or tarred paper as shown on the drawings.

80. **Protecting Expansion Joints.**—At expansion joints the edges of the concrete shall be protected by steel plates approved by the engineer and the joints shall be filled with an asphaltic felt.

The centering under the steel trusses shall be lowered and the trusses swung free on their own bearing before the concrete is run for the floor.

On long spans unless provision is made for reversal of stresses in the trusses, concreting of the floors shall be carried on from each end simultaneously.

81. **Protection During Curing.**—The exposed surfaces of all concrete placed in floors shall be protected from the direct rays of the sun by canvas, or other method of covering approved by the engineer. All concrete shall be kept moist for a minimum of one week. Adequate water supply shall be provided by the contractor, and the curing of the conrecte shall be carried on in detail as directed by the engineer.

82. **Bituminous Floor Coating.**—A tar or asphalt of quality acceptable to the engineer and Commission shall be applied hot to the concrete at the rate of one-third gallon per square yard. Over this coating while hot shall be sifted, hot, clean, dry sand, screened through a ¼-inch mesh. The sand shall be placed in excess and rolled with a hand roller. All joints and corners shall be thoroughly filled with the asphalt or tar.

The county reserves the right to specify the tar or asphalt to be used, and the method of application and temperatures shall be in strict accordance with the written directions furnished the contractor by the engineer. All concrete surfaces to be covered with the bituminous coating shall be cleaned with steel brooms and blown free of all loose particles of any character.

If such coating is desired, it shall be specified in the instruction to bidders.

83. **Drainage Pipes.**—On all truss spans provision for floor drainage shall be made by providing and placing 4-inch cast iron drain pipes with perforated cast iron covers. On pony truss spans without joists one drain pipe shall be located in each end panel and in each alternate intermediate panel on both sides of the bridge. On truss spans with joists one drain pipe shall be located in each panel on both sides of the bridge.

84. **Reinforcement Steel.**—All reinforcement steel used in concrete floors shall meet the requirements of Section 3, Paragraph 29.

85. **Sidewalks.**—Sidewalks where built shall conform to the requirements of the incorporation in which they are built. Dimensions and details shall be shown on the plans.

86. **Creosote Wood Floors.**—*Creosote wood block floors* may be laid over a creosote sub-plank or concrete base, but in either case all creosoted material used shall conform to the following requirements:

Timber

87. **Creosoted Material.**—All timber used in wood block bridge floor construction shall be creosoted. This includes sub-plank, sheathing, retaining pieces, scupper blocks, felloe guards, spiking pieces and paving blocks.

88. **Quality.**—The paving blocks shall be cut from Dense Southern Yellow Pine conforming to the density rules as adopted by the American Society for Testing Materials, August, 1915.

The lumber shall be cut from Southern Yellow Pine of the same quality as specified above for the paving blocks, or from Douglas Fir.

The material for the lumber and blocks shall be well manufactured, square-edged, and free from bark, shakes, large, loose or rotten knots, or other defects which may be detrimental to its strength or durability.

89. **Dimensions.**—The lumber shall be of the standard commercial dimensions corresponding to the nominal dimensions shown on the plans or

noted in these specifications. Felloe guards, scupper blocks, and retaining pieces shall be surfaced one side and one edge.

The paving blocks shall have a minimum length of 6 inches and a maximum length of 10 inches. They shall be 4 inches wide and 3 inches deep, surfaced one side and one edge, and shall not vary in width more than ⅛ inch or in thickness more than 1/16 inch.

Wherever possible all material including scupper blocks shall be cut to size before being treated. The ends of all material sawed in the field shall be dipped in hot creosote oil before being put in place.

Treatment

90. **Treatment of Lumber and Blocks.**—The timber shall be placed in an air-tight cylinder where, by means of steam and a vacuum pump, the sap will be vaporized and the moisture removed. During the process of steaming which shall last at least three hours, a vent shall be kept open in the cylinder to permit the escape of water, air and condensed steam from the cylinder. After the heating or steaming period, the drain or vent in the bottom of the cylinder shall be opened and all moisture removed from the cylinder. During the vacuum period the temperature in the cylinder must be above the boiling point of water under existing vacuum. When the cylinder is thoroughly drained a vacuum of not less than twenty inches of mercury shall be maintained.

When the timber is thoroughly dry the cylinder shall be filled with oil following a vacuum of not less than twenty inches of mercury and pressure shall then be applied and increased gradually to not more than two hundred (200) pounds per square inch and maintained until sufficient oil is forced into the timber to insure that it is thoroughly impregnated and that the amount retained per cubic foot of timber shall be not less than 16 pounds for the paving blocks and not less than 12 pounds for the dimension lumber.

The pressure period on the oil shall be continuous and of a duration of not less than three (3) hours. After the surrounding oil has been removed, the timber shall remain in the closed cylinder for a period of thirty (30) minutes to allow the excess oil on the surface of the timber to drain off. The oil thus drained off shall be forced back into the treating tank in order to determine the amount of impregnation.

The temperature of the oil after entering the cylinder shall be not lower than one hundred and sixty-five degrees Fahrenheit. The cylinder shall be provided with sufficient steam coils to fully maintain this temperature throughout injection.

The oil tanks and cylinder in which the timber is treated shall be equipped with the necessary gauges, thermometers, and drawcocks in order to facilitate a thorough inspection of the materials and treatments.

The plant shall be provided with proper means for obtaining the absolute measurement and weight of all oils entering the cylinder and the amount of oil retained by the timber.

91. **Notification of Treatment.**—The creosoting company shall notify the State Highway Commission a sufficient length of time before the material is to be treated so that an inspector may be furnished at the plant to inspect the material and check the treatment.

92. **Plant Inspection Waived.**—Should the creosoting company be notified in writing that plant inspection will be waived, the creosoting company will be required to furnish a certified statement, signed by proper officers of the company, which statement shall indicate the amount of creosoted oil injected and remaining in the timber, and the results of analysis of the oil, which analysis shall be made in accordance with the methods described in these specifications.

93. **Failure to Give Notice of Treatment.**—Should the creosoting company fail to notify the State Highway Commission of the date the material is to be treated, as heretofore provided, then field determination of the quantity of creosote contained in the lumber or blocks may be made in such manner as the Highway Commission may desire, and if in their opinion the timber contains less creosote oil than required by the specifications, it shall be rejected.

Creosote Oil

94. **General Character.**—The oil shall be a distillate obtained wholy from coal tar without the admixture of any other material.

The oil shall contain not more than one per cent. (1 %) of matter insoluble in hot benzol or chloroform.

95. **Distilling Test.**—The oil shall be subject to a distilling test as follows: The apparatus for distilling the creosote must consist of a stoppered glass retort having a capacity, as nearly as can be obtained, of eight ounces up to the bend of the neck, when the bottom of the retort and the mouth of the takeoff are in the same plane. The bulb of the thermometer shall be placed one-half (½) inch above the liquid in the retort at the beginning of the distillation, and this position must be maintained through the operation. The condensing tube shal. be attached to the retort by a tight cork joint. The distance between the thermometer and the end of the condensing tube shall be twenty-two (22) inches, and during the process of the distillation the tube may be heated to prevent the congealing of the distillates. The bulb of the retort and at least two (2) inches of the neck must be covered with a shield of heavy asbestos paper during the entire process of distillation, so as to prevent heat radiation, and between the bottom of the retort and the flame of the lamp or burner two sheets of wire gauze each twenty (20) mesh fine and at least six (6) inches square must be placed. The flame must be protected against air currents.

The distillation shall be continuous and uniform, the heat being applied gradually. It shall be at a rate approximately one (1) drop per second, and shall take from thirty (30) to forty (40) minutes after the first drop of distillate passes into the receiving vessel. One hundred grams of the oil shall be taken for distillation. The distillates shall be collected in weighed bottles and all percentages determined by weight in comparison with dry oil.

96. **Oil for Paving Blocks and Dimension Lumber.**—The specific gravity of the oil at 38 degrees Centigrade shall be not less than 1.03 and not more than 1.08.

When subjected to the distilling test described above the amount of distillate shall not exceed the following:

Up to 200 degrees C., no distillate.
Up to 210 degrees C., not to exceed 5 %.
Up to 235 degrees C., not to exceed 25 %.

The residue at 355 degrees C. if it exceeds 5 % shall be soft. The oil shall be a pure distillate of coke-oven tar or coal-gas tar without the admixture of any other material. It shall be completely liquid at 38 degrees C., shall contain no suspended matter and shall contain not to exceed 3 % of water.

Asphalt Filler

The asphalt used for block filler and expansion joints shall conform to the following requirements, the various properties to be determined by the methods proposed by the American Society for Testing Materials.

97. **Specific Gravity.**—The asphalt shall have a specific gravity at 25 degrees C. of not less than 0.97 nor more than 1.06.

98. **Total Bitumen.**—The asphalt shall be soluble in cold carbon disulphide to the extent of at least 98 %.

99. **Naphtha Insoluble Bitumen.**—Of the total bitumen, not less than twenty (20) per cent. nor more than thirty (30) per cent. shall be insoluble in 86 degrees B. naphtha.

100. **Loss on Evaporation.**—When 20 grams (in a tin dish 2½ inches in diameter and ¾ inch deep with vertical sides) are maintained at a temperature of 163 degrees C. for 5 hours in a N. Y. testing laboratory oven, the evaporation loss shall not exceed 2 % and the penetration shall not have been decreased more than 35 %.

101. **Fixed Carbon.**—The fixed carbon shall not exceed 16 % by weight.

102. **Penetration.**—The penetration as determined with the Dow machine using a No. 2 needle, 100 gm. weight, 5 seconds time, and a temperature of 25 degrees C. shall not be less than 3.0 mm. nor more than 5.0 mm.

103. **Paraffine.**—The asphalt shall not contain to exceed 4 % by weight of paraffine scale.

Construction

104. **Spiking Pieces.**—The spiking pieces shall be of the sizes shown on the plans and shall be securely bolted to the channels or I-beams as indicated.

105. **Sub-planks.**—The sub-planks shall be 2″ × 12″ and shall be laid at right angles to the roadway with tight joints.

Each plank shall be securely double spiked to each longitudinal spiking piece.

106. **Sheathing.**—On top of the sub-plank 1" sheathing shall be laid at an angle of 45 degrees with the axis of the bridge. It shall be laid with tight joints and securely nailed to the sub-plank.

107. **Retaining Pieces.**—The side retaining pieces shall be spiked and bolted in position as shown on the plans. The end retaining pieces shall be securely spiked in place.

108. **Scupper Blocks.**—The scupper blocks shall be securely fastened to the retaining pieces by means of spikes in addition to the bolts shown on the plans.

109. **Felloe Guards.**—The felloe guards shall be fastened on top of the scupper blocks by means of ¾ inch bolts at each end of each piece and at each intermediate scupper block. These bolts shall extend through the felloe guard, scupper block, retaining piece, as shown on the plans.

110. **Washers.**—Standard size cast or wrought iron Ogee washers shall be used under all bolt heads or nuts which would otherwise come in contact with wood.

111. **Laying the Blocks.**—The blocks shall be thoroughly sprinkled the night before they are laid. None but whole blocks shall be used except at the ends of the rows. After the sub-plank, sheathing, retaining pieces, etc., are in place all irregularities in the surface of the floor shall be removed. The floor shall then be covered with a thin layer of asphalt filler as specified above and the creosoted blocks immediately laid thereon before the asphalt has had time to cool. To insure that the asphalt will be hot when the blocks are set it shall be spread on the floor for only a short distance in front of the block laying.

The block shall be laid with the grain vertical and in regular courses at right angles to the center line of roadway. They shall be laid with ⅛ inch joints all around them and the blocks in adjacent rows shall break joints by at least 3 inches. The ⅛ inch transverse joints between the rows of blocks shall be secured by the use of a ⅛ inch steel plate or template which shall extend the full width of the roadway. Immediately after the blocks are laid they shall be tamped until firmly bedded in the asphalt.

112. **Expansion Joints.**—An expansion joint one inch wide shall be provided along each retaining piece and shall be kept free from obstruction during construction by a wood strip one inch thick extending down to the sheathing.

113. **Filling Joints.**—After the blocks have been laid and tamped the wood strips shall be removed from the expansion joints and all joints over the entire surface of the roadway shall then be filled with the asphalt filler which shall be applied at a temperature of not less than 400° F. After the filler has been applied the entire surface shall be covered with a light coating of clean, coarse, dry sand.

PART IV

GENERAL TABLES AND FORMULÆ

CONVERSION TABLE 68

Linear Units

Old Surveyors' Units

1 link = 7.92 in.
100 links = 1 chain = 66 ft.
25 links = 1 rod = 16.5 ft.

Ordinary Measure

12 in. = 1 ft.
3 ft. = 1 yd.
5280 ft. = 1 mile

Square Units

1 sq. ft.	= 144 sq. in.
1 sq. yd.	= 9 sq. ft.
	= 1296 sq. in.
1 acre	= 43,560 sq. ft.
	= 4840 sq. yds.
1 sq. mile	= 27,878,400 sq. ft.
	= 3,097,600 sq. yds.
	= 640 acres

Volume Units

1 cu. ft.	= 1728 cu. in.
	= 7.4805 ordinary gal.
	= 6.232 Imperial gal.
1 cu. yd.	= 27 cu. ft.
	= 46,656 cu. in.
1 ordinary gal.	= 231 cu. in.
1 Imperial gal.	= 277 cu. in.
1 barrel	= 31.5 gal.
	= 4.21 cu. ft.

Weight Units

1 pound	= 16 ounces
1 ordinary ton	= 2000 pounds
1 long ton	= 2240 pounds

Temperature Units

Freezing point of water	= 32° Fahrenheit
	= 0° Centigrade
Boiling point of water at normal air pressure	= 212° Fahrenheit
	= 100° Centigrade
1 degree Fahrenheit	= 0.5556 degree Centigrade
1 degree Centigrade	= 1.8 degrees Fahrenheit

Table 69

Equivalents of Inches and Fractions of Inches in Decimals of a Foot

In.	0 In.	1 In.	2 In.	3 In.	4 In.	5 In.
		.0833	.1667	.2500	.3333	.4167
$\frac{1}{32}$	.0026	.0859	.1693	.2526	.3359	.4193
$\frac{1}{16}$	.0052	.0885	.1719	.2552	.3385	.4219
$\frac{3}{32}$	.0078	.0911	.1745	.2578	.3411	.4245
$\frac{1}{8}$	.0104	.0938	.1771	.2604	.3438	.4271
$\frac{5}{32}$	.0130	.0964	.1797	.2630	.3464	.4297
$\frac{3}{16}$	.0156	.0990	.1823	.2656	.3490	.4323
$\frac{7}{32}$	.0182	.1016	.1849	.2682	.3516	.4349
$\frac{1}{4}$	.0208	.1042	.1875	.2708	.3542	.4375
$\frac{9}{32}$	.0234	.1068	.1901	.2734	.3568	.4401
$\frac{5}{16}$	.0260	.1094	.1927	.2760	.3594	.4427
$\frac{11}{32}$	.0286	.1120	.1953	.2786	.3620	.4453
$\frac{3}{8}$	.0313	.1146	.1979	.2813	.3646	.4479
$\frac{13}{32}$	.0339	.1172	.2005	.2839	.3672	.4505
$\frac{7}{16}$	.0365	.1198	.2031	.2865	.3698	.4531
$\frac{15}{32}$	.0391	.1224	.2057	.2891	.3724	.4557
$\frac{1}{2}$	.0417	.1253	.2083	.2917	.3750	.4583
$\frac{17}{32}$	.0443	.1276	.2091	.2943	.3776	.4609
$\frac{9}{16}$	.0469	.1302	.2135	.2969	.3802	.4635
$\frac{19}{32}$	.0495	.1328	.2161	.2995	.3828	.4661
$\frac{5}{8}$	.0521	.1354	.2188	.3021	.3854	.4688
$\frac{21}{32}$	.0547	.1380	.2214	.3047	.3880	.4714
$\frac{11}{16}$	.0573	.1406	.2240	.3073	.3906	.4740
$\frac{23}{32}$	.0599	.1432	.2266	.3099	.3932	.4766
$\frac{3}{4}$	.0625	.1458	.2292	.3125	.3958	.4792
$\frac{25}{32}$	.0651	.1484	.2318	.3151	.3984	.4818
$\frac{13}{16}$	.0677	.1510	.2344	.3177	.4010	.4844
$\frac{27}{32}$	.0703	.1536	.2370	.3203	.4036	.4870
$\frac{7}{8}$	.0729	.1563	.2396	.3229	.4063	.4896
$\frac{29}{32}$	.0755	.1589	.2422	.3255	.4089	.4922
$\frac{15}{16}$	.0781	.1615	.2448	.3281	.4115	.4948
$\frac{31}{32}$	.0807	.1641	.2474	.3307	.4141	.4974

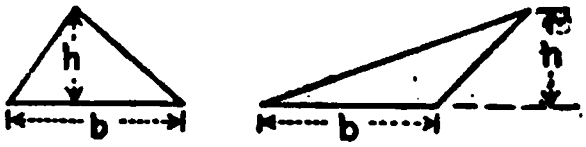
Equivalents of Inches and Fractions of Inches in Decimals of a Foot

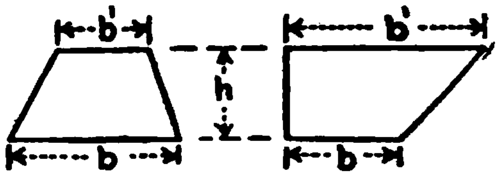
In.	6 In.	7 In.	8 In.	9 In.	10 In.	11 In.
	.5000	.5833	.6667	.7500	.8333	.9167
1/32	.5026	.5859	.6693	.7526	.8359	.9193
1/16	.5052	.5885	.6719	.7552	.8385	.9219
3/32	.5078	.5911	.6745	.7578	.8411	.9245
1/8	.5104	.5938	.6771	.7604	.8438	.9271
5/32	.5130	.5964	.6797	.7630	.8464	.9297
3/16	.5156	.5990	.6823	.7656	.8490	.9323
7/32	.5182	.6016	.6849	.7682	.8516	.9349
1/4	.5208	.6042	.6875	.7708	.8542	.9375
9/32	.5234	.6068	.6901	.7734	.8568	.9401
5/16	.5260	.6094	.6927	.7760	.8594	.9427
11/32	.5286	.6120	.6953	.7786	.8620	.9453
3/8	.5313	.6146	.6979	.7813	.8646	.9479
13/32	.5339	.6172	.7005	.7839	.8672	.9505
7/16	.5365	.6198	.7031	.7865	.8698	.9531
15/32	.5391	.6224	.7057	.7891	.8724	.9557
1/2	.5417	.6250	.7083	.7917	.8750	.9583
17/32	.5443	.6276	.7109	.7943	.8776	.9609
9/16	.5469	.6302	.7135	.7969	.8802	.9635
19/32	.5495	.6328	.7161	.7995	.8828	.9661
5/8	.5521	.6354	.7188	.8021	.8854	.9688
21/32	.5547	.6380	.7214	.8047	.8880	.9714
11/16	.5573	.6406	.7240	.8073	.8906	.9740
23/32	.5599	.6432	.7266	.8099	.8932	.9766
3/4	.5625	.6458	.7292	.8125	.8958	.9792
25/32	.5651	.6484	.7318	.8151	.8984	.9818
13/16	.5677	.6510	.7344	.8177	.9010	.9844
27/32	.5703	.6536	.7370	.8203	.9036	.9870
7/8	.5729	.6563	.7396	.8229	.9063	.9896
29/32	.5755	.6589	.7422	.8255	.9089	.9922
15/16	.5781	.6615	.7448	.8281	.9115	.9948
31/32	.5807	.6641	.7474	.8307	.9141	.9974

Table 70. Areas and Volumes

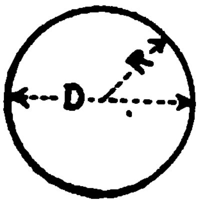
Areas

Squares, Rectangles, and Parallelograms. Area $= bh$





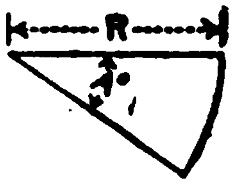
Triangles Area $= \frac{1}{2}\, bh$ *Trapezoids* Area $= \frac{b + b'}{2} h$



Circles

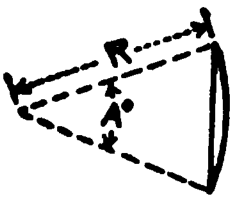
$$\text{Area} = \pi R^2 = \frac{\pi D^2}{4}$$

Circumference of Circle $= 2\pi R = \pi D$
Commonly used value of $\pi = 3.1416$



Sector of Circle

$$\text{Area} = \pi R^2 \frac{A^\circ}{360^\circ}$$



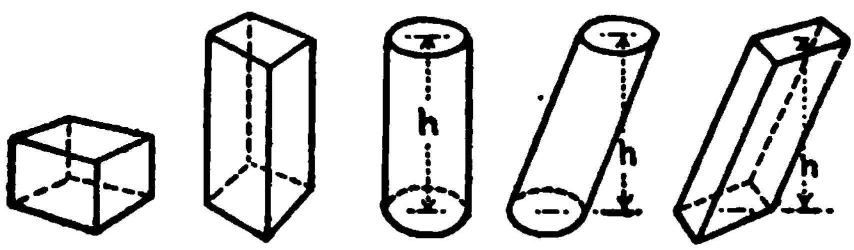
Segment of a Circle

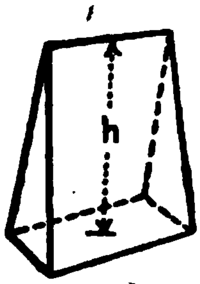
$$\text{Area} = \left(\pi R^2 \frac{A^\circ}{360^\circ}\right) - \left(\left(R \sin \frac{A}{2}\right)\left(R \cos \frac{A}{2}\right)\right)$$

Volumes

Cubes, Rectangular Prisms, Parallelopipeds, Cylinders, etc. All solids having parallel bases and a constant cross-section.

Volume = area of base × perpendicular height between the planes of the bases.



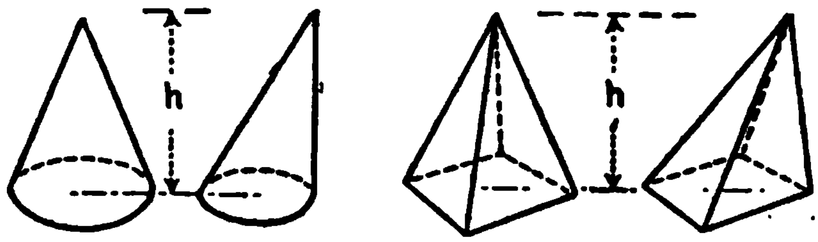


Wedges. Having parallel ends.

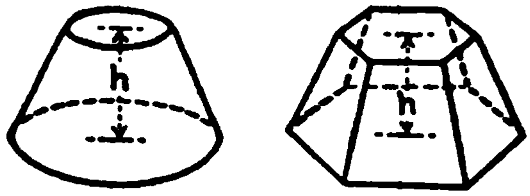
Volume = area of base × $\frac{1}{2}$ the height perpendicular to the plane of the base.

Cones and Pyramids, whether right or oblique, regular or irregular.

Volume = $\frac{1}{3}$ area of the base × height perpendicular to the plane of the base



Frustums of Pyramids or Cones, whether right or oblique, regular or irregular provided the base and top are parallel.



Volume = $\frac{1}{3}$ perpendicular height between base and top × $\left(\text{area top} + \text{area base} + \sqrt{\text{area top} \times \text{area base}}\right)$

or by the prismoidal formula

Volume = $\frac{1}{6}$ perpendicular height between base and top × $\left(\text{area top} + \text{area base} + 4 \times \text{area of section parallel to and midway between base and top}\right)$

Prismoidal Formula

Trautwine defines a prismoid as a solid having for its ends two parallel plane figures connected by other plane figures on which and through every point of which a straight line may be drawn from one of the two parallel ends to the other. These connecting planes may be parallelograms or not and parallel to each other or not. This includes cubes, all parallelopipeds, prisms, cylinders, pyramids, cones, and their frustums, provided the top and base are parallel and wedges.

The prismoidal formula applies to all these solids either alone or to any form that can be separated into units of the above forms.

Prismoidal formulæ

$$\text{Volume} = h \times \frac{A + a + 4M}{6}$$

h = perpendicular distance between the parallel ends
A = area of one of the parallel ends
a = area of the other parallel end
M = area of a cross-section midway between and parallel to the two parallel ends

Sphere

$$\text{Volume} = \tfrac{4}{3}\pi R^3 = 4.1888\ R^3$$
$$= \tfrac{1}{6}\pi D^3 = 0.5236\ D^3$$

In which R = radius of sphere
D = diameter of sphere

TABLE 71

SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, CIRCUMFERENCES AND CIRCULAR AREAS OF NOS. FROM 1 TO 520

No.	Square	Cube	Sq. Root	Cube Root	Circle	
					Circum.	Area
1	1	1	1.0000	1.0000	3.142	0.7854
2	4	8	1.4142	1.2599	6.283	3.1416
3	9	27	1.7321	1.4422	9.425	7.0686
4	16	64	2.0000	1.5874	12.566	12.5664
5	25	125	2.2361	1.7100	15.708	19.6350
6	36	216	2.4495	1.8171	18.850	28.2743
7	49	343	2.6458	1.9129	21.991	38.4845
8	64	512	2.8284	2.0000	25.133	50.2655
9	81	729	3.0000	2.0801	28.274	63.6173
10	100	1000	3.1623	2.1544	31.416	78.5398
11	121	1331	3.3166	2.2240	34.558	95.033
12	144	1728	3.4641	2.2894	37.699	113.097
13	169	2197	3.6056	2.3513	40.841	132.732
14	196	2744	3.7417	2.4101	43.982	153.938
15	225	3375	3.8730	2.4662	47.124	176.715
16	256	4096	4.0000	2.5198	50.265	201.062
17	289	4913	4.1231	2.5713	53.407	226.980
18	324	5832	4.2426	2.6207	56.549	254.469
19	361	6859	4.3589	2.6684	59.690	283.529
20	400	8000	4.4721	2.7144	62.832	314.159
21	441	9261	4.5826	2.7589	65.973	346.361
22	484	10648	4.6904	2.8020	69.115	380.133
23	529	12167	4.7958	2.8439	72.257	415.476
24	576	13824	4.8990	2.8845	75.398	452.389
25	625	15625	5.0000	2.9240	78.540	490.874
26	676	17576	5.0990	2.9625	81.681	530.929
27	729	19683	5.1962	3.0000	84.823	572.555
28	784	21952	5.2915	3.0366	87.965	615.752
29	841	24389	5.3852	3.0723	91.106	660.520
30	900	27000	5.4772	3.1072	94.248	706.858
31	961	29791	5.5678	3.1414	90.389	754.768
32	1024	32768	5.6569	3.1748	100.531	804.248
33	1089	35937	5.7446	3.2075	103.673	855.299
34	1156	39304	5.8310	3.2396	106.814	907.920
35	1225	42875	5.9161	3.2711	109.956	962.113
36	1296	46656	6.0000	3.3019	113.097	1017.88
37	1369	50653	6.0828	3.3322	116.239	1075.21
38	1444	54872	6.1644	3.3620	119.381	1134.11
39	1521	59319	6.2450	3.3912	122.522	1194.59
40	1600	64000	6.3246	3.4200	125.660	1256.64

Squares, Cubes, Square Roots, Cube Roots, Circumferences and Circular Areas of Nos. from 1 to 520

No.	Square	Cube	Sq. Root	Cube Root	Circle Circum.	Circle Area
41	1681	68921	6.4031	3.4482	128.81	1320.25
42	1764	74088	6.4807	3.4760	131.95	1385.44
43	1849	79507	6.5574	3.5034	135.09	1452.20
44	1936	85184	6.6332	3.5303	138.23	1520.53
45	2025	91125	6.7082	3.5569	141.37	1590.43
46	2116	97336	6.7823	3.5830	144.51	1661.90
47	2209	103823	6.8557	3.6088	147.65	1734.94
48	2304	110592	6.9282	3.6342	150.80	1809.56
49	2401	117649	7.0000	3.6593	153.94	1885.74
50	2500	125000	7.0711	3.6840	157.08	1963.50
51	2601	132651	7.1414	3.7084	160.22	2042.82
52	2704	140608	7.2111	3.7325	163.36	2123.72
53	2809	148877	7.2801	3.7563	166.50	2206.18
54	2916	157464	7.3485	3.7798	169.65	2290.22
55	3025	166375	7.4162	3.8030	172.79	2375.83
56	3136	175616	7.4833	3.8259	175.93	2463.01
57	3249	185193	7.5498	3.8485	179.07	2551.76
58	3364	195112	7.6158	3.8709	182.21	2642.08
59	3481	205379	7.6811	3.8930	185.35	2733.97
60	3600	216000	7.7460	3.9149	188.50	2827.43
61	3721	226981	7.8102	3.9365	191.64	2922.47
62	3844	238328	7.8740	3.9579	194.78	3019.07
63	3969	250047	7.9373	3.9791	197.92	3117.25
64	4096	262144	8.0000	4.0000	201.06	3216.99
65	4225	274625	8.0623	4.0207	204.20	3318.31
66	4356	287496	8.1240	4.0412	207.35	3421.19
67	4489	300763	8.1854	4.0615	210.49	3525.65
68	4624	314432	8.2462	4.0817	213.63	3631.68
69	4761	328509	8.3066	4.1016	216.77	3739.28
70	4900	343000	8.3666	4.1213	219.91	3848.45
71	5041	357911	8.4261	4.1408	223.05	3959.19
72	5184	373248	8.4853	4.1602	226.19	4071.50
73	5329	389017	8.5440	4.1793	229.34	4185.39
74	5476	405224	8.6023	4.1983	232.48	4300.84
75	5625	421875	8.6603	4.2172	235.62	4417.86
76	5776	438976	8.7178	4.2358	238.76	4536.46
77	5929	456533	8.7750	4.2543	241.90	4656.63
78	6084	474552	8.8318	4.2727	245.04	4778.36
79	6241	493039	8.8882	4.2908	248.19	4901.67
80	6400	512000	8.9443	4.3089	251.33	5026.55

SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, CIRCUMFERENCES AND CIRCULAR AREAS OF NOS. FROM 1 TO 520

No.	Square	Cube	Sq. Root	Cube Root	Circle	
					Circum.	Area
81	6561	531441	9.0000	4.3267	254.47	5153.00
82	6724	551368	9.0554	4.3445	257.61	5281.02
83	6889	571787	9.1104	4.3621	260.75	5410.61
84	7056	592704	9.1652	4.3795	263.89	5541.77
85	7225	614125	9.2195	4.3968	267.04	5674.50
86	7396	636056	9.2736	4.4140	270.18	5808.80
87	7569	658503	9.3274	4.4310	273.32	5944.68
88	7744	681472	9.3808	4.4480	276.46	6082.12
89	7921	704969	9.4340	4.4647	279.60	6221.14
90	8100	729000	9.4868	4.4814	282.74	6361.73
91	8281	753571	9.5394	4.4979	285.88	6503.88
92	8464	778688	9.5917	4.5144	289.03	6647.61
93	8649	804357	9.6437	4.5307	292.17	6792.91
94	8836	830584	9.6954	4.5468	295.31	6939.78
95	9025	857375	9.7468	4.5629	298.45	7088.22
96	9216	884736	9.7980	4.5789	301.59	7238.23
97	9409	912673	9.8489	4.5947	304.73	7389.81
98	9604	941192	9.8995	4.6104	307.88	7542.96
99	9801	970299	9.9499	4.6261	311.02	7697.69
100	10000	1000000	10.0000	4.6416	314.16	7853.98
101	10201	1030301	10.0499	4.6570	317.30	8011.85
102	10404	1061208	10.0995	4.6723	320.44	8171.28
103	10609	1092727	10.1489	4.6875	323.58	8332.29
104	10816	1124864	10.1980	4.7027	326.73	8494.87
105	11025	1157625	10.2470	4.7177	329.87	8659.01
106	11236	1191016	10.2956	4.7326	333.01	8824.73
107	11449	1225043	10.3441	4.7475	336.15	8992.02
108	11664	1259712	10.3923	4.7622	339.29	9160.88
109	11881	1295029	10.4403	4.7769	342.43	9331.32
110	12100	1331000	10.4881	4.7914	345.58	9503.32
111	12321	1367631	10.5357	4.8059	348.72	9676.89
112	12544	1404928	10.5830	4.8203	351.86	9852.03
113	12769	1442897	10.6301	4.8346	355.00	10028.7
114	12996	1481544	10.6771	4.8488	358.14	10207.0
115	13225	1520875	10.7238	4.8629	361.28	10386.9
116	13456	1560896	10.7703	4.8770	364.42	10568.3
117	13689	1601613	10.8167	4.8910	367.57	10751.3
118	13924	1643032	10.8628	4.9049	370.71	10935.9
119	14161	1685159	10.9087	4.9187	373.85	11122.0
120	14400	1728000	10.9545	4.9324	376.99	11309.7

Squares, Cubes, Square Roots, Cube Roots, Circumferences and Circular Areas of Nos. from 1 to 520

No.	Square	Cube	Sq. Root	Cube Root	Circle Circum.	Circle Area
121	14641	1771561	11.0000	4.9461	380.13	11499.0
122	14884	1815848	11.0454	4.9597	383.27	11689.9
123	15129	1860867	11.0905	4.9732	386.42	11882.3
124	15376	1906624	11.1355	4.9866	389.56	12076.3
125	15625	1953125	11.1803	5.0000	392.70	12271.8
126	15876	2000376	11.2250	5.0133	395.84	12469.0
127	16129	2048383	11.2694	5.0265	398.98	12667.7
128	16384	2097152	11.3137	5.0397	402.12	12868.0
129	16641	2146689	11.3578	5.0528	405.27	13069.8
130	16900	2197000	11.4018	5.0658	408.41	13273.2
131	17161	2248091	11.4455	5.0788	411.55	13478.2
132	17424	2299968	11.4891	5.0916	414.69	13684.8
133	17689	2352637	11.5326	5.1045	417.83	13892.9
134	17956	2406104	11.5758	5.1172	420.97	14102.6
135	18225	2460375	11.6190	5.1299	424.12	14313.9
136	18496	2515456	11.6619	5.1426	427.26	14526.7
137	18769	2571353	11.7047	5.1551	430.40	14741.1
138	19044	2628072	11.7473	5.1676	433.54	14957.1
139	19321	2685619	11.7898	5.1801	436.68	15174.7
140	19600	2744000	11.8322	5.1925	439.82	15393.8
141	19881	2803221	11.8743	5.2048	442.96	15614.5
142	20164	2863288	11.9164	5.2171	446.11	15836.8
143	20449	2924207	11.9583	5.2293	449.25	16060.6
144	20736	2985984	12.0000	5.2415	452.39	16286.0
145	21025	3048625	12.0416	5.2536	455.53	16513.0
146	21316	3112136	12.0830	5.2656	458.67	16741.5
147	21609	3176523	12.1244	5.2776	461.81	16971.7
148	21904	3241792	12.1655	5.2896	464.96	17203.4
149	22201	3307949	12.2066	5.3015	468.10	17436.6
150	22500	3375000	12.2474	5.3133	471.24	17671.5
151	22801	3442951	12.2882	5.3251	474.38	17907.9
152	23104	3511808	12.3288	5.3368	477.52	18145.8
153	23409	3581577	12.3693	5.3485	480.66	18385.4
154	23716	3652264	12.4097	5.3601	483.81	18626.5
155	24025	3723875	12.4499	5.3717	486.95	18869.2
156	24336	3796416	12.4900	5.3832	490.09	19113.4
157	24649	3869893	12.5300	5.3947	493.23	19359.3
158	24964	3944312	12.5698	5.4061	496.37	19606.7
159	25281	4019679	12.6095	5.4175	499.51	19855.7
160	25600	4096000	12.6491	5.4288	502.65	20106.2

SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, CIRCUMFERENCES AND CIRCULAR AREAS OF NOS. FROM 1 TO 520

No.	Square	Cube	Sq. Root	Cube Root	Circle: Circum.	Circle: Area
161	25921	4173281	12.6886	5.4401	505.80	20358.3
162	26244	4251528	12.7279	5.4514	508.94	20612.0
163	26569	4330747	12.7671	5.4626	512.08	20867.2
164	26896	4410944	12.8062	5.4737	515.22	21124.1
165	27225	4492125	12.8452	5.4848	518.36	21382.5
166	27556	4574296	12.8841	5.4959	521.50	21642.4
167	27889	4657463	12.9228	5.5069	524.65	21904.0
168	28224	4741632	12.9615	5.5178	527.79	22167.1
169	28561	4826809	13.0000	5.5288	530.93	22431.8
170	28900	4913000	13.0384	5.5397	534.07	22698.0
171	29241	5000211	13.0767	5.5505	537.21	22965.8
172	29584	5088448	13.1149	5.5613	540.35	23235.2
173	29929	5177717	13.1529	5.5721	543.50	23506.2
174	30276	5268024	13.1909	5.5828	546.64	23778.7
175	30625	5359375	13.2288	5.5934	549.78	24052.8
176	30976	5451776	13.2665	5.6041	552.92	24328.5
177	31329	5545233	13.3041	5.6147	556.06	24605.7
178	31684	5639752	13.3417	5.6252	559.20	24884.6
179	32041	5735339	13.3791	5.6357	562.35	25164.9
180	32400	5832000	13.4164	5.6462	565.49	25446.9
181	32761	5929741	13.4536	5.6567	568.63	25730.4
182	33124	6028568	13.4907	5.6671	571.77	26015.5
183	33489	6128487	13.5277	5.6774	574.91	26302.2
184	33856	6229504	13.5647	5.6877	578.05	26590.4
185	34225	6331625	13.6015	5.6980	581.19	26880.3
186	34596	6434856	13.6382	5.7083	584.34	27171.6
187	34969	6539203	13.6748	5.7185	587.48	27464.6
188	35344	6644672	13.7113	5.7287	590.62	27759.1
189	35721	6751269	13.7477	5.7388	593.76	28055.2
190	36100	6859000	15.7840	5.7489	596.90	28352.9
191	36481	6967871	13.8203	5.7590	600.04	28652.1
192	36864	7077888	13.8564	5.7690	603.19	28952.9
193	37249	7189057	13.8924	5.7790	606.33	29255.3
194	37636	7301384	13.9284	5.7890	609.47	29559.2
195	38025	7414875	13.9642	5.7989	612.61	29864.8
196	38416	7529536	14.0000	5.8088	615.75	30171.9
197	38809	7645373	14.0357	5.8186	618.89	30480.5
198	39204	7762392	14.0712	5.8285	622.04	30790.7
199	39601	7880599	14.1067	5.8383	625.18	31102.6
200	40000	8000000	14.1421	5.8480	628.32	31415.9

SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, CIRCUMFERENCES AND CIRCULAR AREAS OF NOS. FROM 1 TO 520

No.	Square	Cube	Sq. Root	Cube Root	Circle Circum.	Circle Area
201	40401	8120601	14.1774	5.8578	631.46	31730.9
202	40804	8242408	14.2127	5.8675	634.60	32047.4
203	41209	8365427	14.2478	5.8771	637.74	32365.5
204	41616	8489664	14.2829	5.8868	640.89	32685.1
205	42025	8615125	14.3178	5.8964	644.03	33006.4
206	42436	8741816	14.3527	5.9059	647.17	33329.2
207	42849	8869743	14.3875	5.9155	650.31	33653.5
208	43264	8998912	14.4222	5.9250	653.45	33979.5
209	43681	9129329	14.4568	5.9345	656.59	34307.0
210	44100	9261000	14.4914	5.9439	659.73	34636.1
211	44521	9393931	14.5258	5.9533	662.88	34966.7
212	44944	9528128	14.5602	5.9627	666.02	35298.9
213	45369	9663597	14.5945	5.9721	669.16	35632.7
214	45796	9800344	14.6287	5.9814	672.30	35968.1
215	46225	9938375	14.6629	5.9907	675.44	36305.0
216	46656	10077696	14.6969	6.0000	678.58	36643.5
217	47089	10218313	14.7309	6.0092	681.73	36983.6
218	47524	10360232	14.7648	6.0185	684.87	37325.3
219	47961	10503459	14.7986	6.0277	688.01	37668.5
220	48400	10648000	14.8324	6.0368	691.15	38013.3
221	48841	10793861	14.8661	6.0459	694.29	38359.6
222	49284	10941048	14.8997	6.0550	697.43	38707.6
223	49729	11089567	14.9332	6.0641	700.58	39057.1
224	50176	11239424	14.9666	6.0732	703.72	39408.1
225	50625	11390625	15.0000	6.0822	706.86	39760.8
226	51076	11543176	15.0333	6.0912	710.00	40115.0
227	51529	11697083	15.0665	6.1002	713.14	40470.8
228	51984	11852352	15.0997	6.1091	716.28	40828.1
229	52441	12008989	15.1327	6.1180	719.42	41187.1
230	52900	12167000	15.1658	6.1269	722.57	41547.6
231	53361	12326391	15.1987	6.1358	725.71	41909.6
232	53824	12487168	15.2315	6.1446	728.85	42273.3
233	54289	12649337	15.2643	6.1534	731.99	42638.5
234	54756	12812904	15.2971	6.1622	735.13	43005.3
235	55225	12977875	15.3297	6.1710	738.27	43373.6
236	55696	13144256	15.3623	6.1797	741.42	43743.5
237	56169	13312053	15.3948	6.1885	744.56	44115.0
238	56644	13481272	15.4272	6.1972	747.70	44488.1
239	57121	13651919	15.4596	6.2058	750.84	44862.7
240	57600	13824000	15.4919	6.2145	753.98	45238.9

SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, CIRCUMFERENCES AND CIRCULAR AREAS OF NOS. FROM 1 TO 520

No.	Square	Cube	Sq. Root	Cube Root	Circle Circum.	Circle Area
241	58081	13997521	15.5242	6.2231	757.12	45616.7
242	58564	14172488	15.5563	6.2317	760.27	45996.1
243	59049	14348907	15.5885	6.2403	763.41	46377.0
244	59536	14526784	15.6205	6.2488	766.55	46759.5
245	60025	14706125	15.6525	6.2573	769.69	47143.5
246	60516	14886936	15.6844	6.2658	772.83	47529.2
247	61009	15069223	15.7162	6.2743	775.97	47916.4
248	61504	15252992	15.7480	6.2828	779.12	48305.1
249	62001	15438249	15.7797	6.2912	782.26	48695.5
250	62500	15625000	15,8114	6.2996	785.40	49087.4
251	63001	15813251	15.8430	6.3080	788.54	49480.9
252	63504	16003008	15.8745	6.3164	791.68	49875.9
253	64009	16194277	15.9060	6.3247	794.82	50272.6
254	64516	16387064	15.9374	6.3330	797.96	50670.7
255	65025	16581375	15.9687	6.3413	801.11	51070.5
256	65536	16777216	16.0000	6.3496	804.25	51471.9
257	66049	16974593	16.0312	6.3579	807.39	51874.8
258	66564	17173512	16.0624	6.3661	810.53	52279.2
259	67081	17373979	16.0935	6.3743	813.67	52685.3
260	67600	17576000	16.1245	6.3825	816.81	53092.9
261	68121	17779581	16.1555	6.3907	819.96	53502.1
262	68644	17984728	16.1864	6.3988	823.10	53912.9
263	69169	18191447	16.2173	6.4070	826.24	54325.2
264	69696	18399744	16.2481	6.4151	829.38	54739.1
265	70225	18609625	16.2788	6.4232	832.52	55154.6
266	70756	18821096	16.3095	6.4312	835.66	55571.6
267	71289	19034163	16.3401	6.4393	838.81	55990.3
268	71824	19248832	16.3707	6.4473	841.95	56410.4
269	72361	19465109	16.4012	6.4553	845.09	56832.2
270	72900	19683000	16.4317	6.4633	848.23	57255.5
271	73441	19902511	16.4621	6.4713	851.37	57680.4
272	73984	20123648	16.4924	6.4792	854.51	58106.9
273	74529	20346417	16.5227	6.4872	857.66	58534.9
274	75076	20570824	16.5529	6.4951	860.80	58964.6
275	75625	20796875	16.5831	6.5030	863.94	59395.7
276	76176	21024576	16.6132	6.5108	867.08	59828.5
277	76729	21253933	16.6433	6.5187	870.22	60262.8
278	77284	21484952	16.6733	6.5265	873.36	60698.7
279	77841	21717639	16.7033	6.5343	876.50	61136.2
280	78400	21952000	16.7332	6.5421	879.65	61575.2

Squares, Cubes, Square Roots, Cube Roots, Circumferences and Circular Areas of Nos. from 1 to 520

No.	Square	Cube	Sq. Root	Cube Root	Circle	
					Circum.	Area
281	78961	22188041	16.7631	6.5499	882.79	62015.8
282	79524	22425768	16.7929	6.5577	885.93	62458.0
283	80089	22665187	16.8226	6.5654	889.07	62901.8
284	80656	22906304	16.8523	6.5731	892.21	63347.1
285	81225	23149125	16.8819	6.5808	895.35	63794.0
286	81796	23393656	16.9115	6.5885	898.50	64242.4
287	82369	23639903	16.9411	6.5962	901.64	64692.5
288	82944	23887872	16.9706	6.6039	904.78	65144.1
289	83521	24137569	17.0000	6.6115	907.92	65597.2
290	84100	24389000	17.0294	6.6191	911.06	66052.0
291	84681	24642171	17.0587	6.6267	914.20	66508.3
292	85264	24897088	17.0880	6.6343	917.35	66966.2
293	85849	25153757	17.1172	6.6419	920.49	67425.6
294	86436	25412184	17.1464	6.6494	923.63	67886.7
295	87025	25672375	17.1756	6.6569	926.77	68349.3
296	87616	25934336	17.2047	6.6644	929.91	68813.5
297	88209	26198073	17.2337	6.6719	933.05	69279.2
298	88804	26463592	17.2627	6.6794	936.19	69746.5
299	89401	26730899	17.2916	6.6869	939.34	70215.4
300	90000	27000000	17.3205	6.6943	942.48	70685.8
301	90601	27270901	17.3494	6.7018	945.62	71157.9
302	91204	27543608	17.3781	6.7092	948.76	71631.5
303	91809	27818127	17.4069	6.7166	951.90	72106.6
304	92416	28094464	17.4356	6.7240	955.04	72583.4
305	93025	28372625	17.4642	6.7313	958.19	73061.7
306	93636	28652616	17.4929	6.7387	961.33	73541.5
307	94249	28934443	17.5214	6.7460	964.47	74023.0
308	94864	29218112	17.5499	6.7533	967.61	74506.0
309	95481	29503629	17.5784	6.7606	970.75	74990.6
310	96100	29791000	17.6068	6.7679	973.89	75476.8
311	96721	30080231	17.6352	6.7752	977.04	75964.5
312	97344	30371328	17.6635	6.7824	980.18	76453.8
313	97969	30664297	17.6918	6.7897	983.32	76944.7
314	98596	30959144	17.7200	6.7969	986.46	77437.1
315	99225	31255875	17.7482	6.8041	989.60	77931.1
316	99856	31554496	17.7764	6.8113	992.74	78426.7
317	100489	31855013	17.8045	6.8185	995.88	78923.9
318	101124	32157432	17.8326	6.8256	999.03	79422.6
319	101761	32461759	17.8606	6.8328	1002.20	79922.9
320	102400	32768000	17.8885	6.8399	1005.30	80424.8

SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, CIRCUMFERENCES AND CIRCULAR AREAS OF NOS. FROM 1 TO 520

No.	Square	Cube	Sq. Root	Cube Root	Circle Circum.	Circle Area
321	103041	33076161	17.9165	6.8470	1008.5	80928.2
322	103684	33386248	17.9444	6.8541	1011.6	81433.2
323	104329	33698267	17.9722	6.8612	1014.7	81939.8
324	104976	34012224	18.0000	6.8683	1017.9	82448.0
325	105625	34328125	18.0278	6.8753	1021.0	82957.7
326	106276	34645976	18.0555	6.8824	1024.2	83469.0
327	106929	34965783	18.0831	6.8894	1027.3	83981.8
328	107584	35287552	18.1108	6.8964	1030.4	84496.3
329	108241	35611289	18.1384	6.9034	1033.6	85012.3
330	108900	35937000	18.1659	6.9104	1036.7	85529.9
331	109561	36264691	18.1934	6.9174	1039.9	86049.0
332	110224	36594368	18.2209	6.9244	1043.0	86569.7
333	110889	36926037	18.2483	6.9313	1046.2	87092.0
334	111556	37259704	18.2757	6.9382	1049.3	87615.9
335	112225	37595375	18.3030	6.9451	1052.4	88141.3
336	112896	37933056	18.3303	6.9521	1055.6	88668.3
337	113569	38272753	18.3576	6.9589	1058.7	89196.9
338	114244	38614472	18.3848	6.9658	1061.9	89727.0
339	114921	38958219	18.4120	6.9727	1065.0	90258.7
340	115600	39304000	18.4391	6.9795	1068.1	90792.0
341	116281	39651821	18.4662	6.9864	1071.3	91326.9
342	116964	40001688	18.4932	6.9932	1074.4	91863.3
343	117649	40353607	18.5203	7.0000	1077.6	92401.3
344	118336	40707584	18.5472	7.0068	1080.7	92940.9
345	119025	41063625	18.5742	7.0136	1083.8	93482.0
346	119716	41421736	18.6011	7.0203	1087.0	94024.7
347	120409	41781923	18.6279	7.0271	1090.1	94569.0
348	121104	42144192	18.6548	7.0338	1093.3	95114.9
349	121801	42508549	18.6815	7.0406	1096.4	95662.3
350	122500	42875000	18.7083	7.0473	1099.6	96211.3
351	123201	43243551	18.7350	7.0540	1102.7	96761.8
352	123904	43614208	18.7617	7.0607	1105.8	97314.0
353	124609	43986977	18.7883	7.0674	1109.0	97867.7
354	125316	44361864	18.8149	7.0740	1112.1	98423.0
355	126025	44738875	18.8414	7.0807	1115.3	98979.8
356	126736	45118016	18.8680	7.0873	1118.4	99538.2
357	127449	45499293	18.8944	7.0940	1121.5	100098
358	128164	45882712	18.9209	7.1006	1124.7	100660
359	128881	46268279	18.9473	7.1072	1127.8	101223
360	129600	46656000	18.9737	7.1138	1131.0	101788

QUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, CIRCUMFERENCES AND CIRCULAR AREAS OF NOS. FROM 1 TO 520

No.	Square	Cube	Sq. Root	Cube Root	Circle Circum.	Circle Area
361	130321	47045881	19.0000	7.1204	1134.1	102354
362	131044	47437928	19.0263	7.1269	1137.3	102922
363	131769	47832147	19.0526	7.1335	1140.4	103491
364	132496	48228544	19.0788	7.1400	1143.5	104062
365	133225	48627125	19.1050	7.1466	1146.7	104635
366	133956	49027896	19.1311	7.1531	1149.8	105209
367	134689	49430863	19.1572	7.1596	1153.0	105785
368	135424	49836032	19.1833	7.1661	1156.1	106362
369	136161	50243409	19.2094	7.1726	1159.2	106941
370	136900	50653000	19.2354	7.1791	1162.4	107521
371	137641	51064811	19.2614	7.1855	1165.5	108103
372	138384	51478848	19.2873	7.1920	1168.7	108687
373	139129	51895117	19.3132	7.1984	1171.8	109272
374	139876	52313624	19.3391	7.2048	1175.0	109858
375	140625	52734375	19.3649	7.2112	1178.1	110447
376	141376	53157376	19.3907	7.2177	1181.2	111036
377	142129	53582633	19.4165	7.2240	1184.4	111628
378	142884	54010152	19.4422	7.2304	1187.5	112221
379	143641	54439939	19.4679	7.2368	1190.7	112815
380	144400	54872000	19.4936	7.2432	1193.8	113411
381	145161	55306341	19.5192	7.2495	1196.9	114009
382	145924	55742968	19.5448	7.2558	1200.1	114608
383	146689	56181887	19.5704	7.2622	1203.2	115209
384	147456	56623104	19.5959	7.2685	1206.4	115812
385	148225	57066625	19.6214	7.2748	1209.5	116416
386	148996	57512456	19.6469	7.2811	1212.7	117021
387	149769	57960603	19.6723	7.2874	1215.8	117628
388	150544	58411072	19.6977	7.2936	1218.9	118237
389	151321	58863869	19.7231	7.2999	1222.1	118847
390	152100	59319000	19.7484	7.3061	1225.2	119459
391	152881	59776471	19.7737	7.3124	1228.4	120072
392	153664	60236288	19.7990	7.3186	1231.5	120687
393	154449	60698457	19.8242	7.3248	1234.6	121304
394	155236	61162984	19.8494	7.3310	1237.8	121922
395	156025	61629875	19.8746	7.3372	1240.9	122542
396	156816	62099136	19.8997	7.3434	1244.1	123163
397	157609	62570773	19.9249	7.3496	1247.2	123786
398	158404	63044792	19.9499	7.3558	1250.4	124410
399	159201	63521199	19.9750	7.3619	1253.5	125036
400	160000	64000000	20.0000	7.3684	1256.6	125664

SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, CIRCUMFERENCES, AND CIRCULAR AREAS OF NOS. FROM 1 TO 520

No.	Square	Cube	Sq. Root	Cube Root	Circle	
					Circum.	Area
401	160801	64481201	20.0250	7.3742	1259.8	126293
402	161604	64964808	20.0499	7.3803	1262.9	126923
403	162409	65450827	20.0749	7.3864	1266.1	127556
404	163216	65939264	20.0998	7.3925	1269.2	128190
405	164025	66430125	20.1246	7.3986	1272.3	128825
406	164836	66923416	20.1494	7.4047	1275.5	129462
407	165649	67419143	20.1742	7.4108	1278.6	130100
408	166464	67917312	20.1990	7.4169	1281.8	130741
409	167281	68417929	20.2237	7.4229	1284.9	131382
410	168100	68921000	20.2485	7.4290	1288.1	132025
411	168921	69426531	20.2731	7.4350	1291.2	132670
412	169744	69934528	20.2978	7.4410	1294.3	133317
413	170569	70444997	20.3224	7.4470	1297.5	133965
414	171396	70957944	20.3470	7.4530	1300.6	134614
415	172225	71473375	20.3715	7.4590	1303.8	135265
416	173056	71991296	20.3961	7.4650	1306.9	135918
417	173889	72511713	20.4206	7.4710	1310.0	136572
418	174724	73034632	20.4450	7.4770	1313.2	137228
419	175561	73560059	20.4695	7.4829	1316.3	137885
420	176400	74088000	20.4939	7.4889	1319.5	138544
421	177241	74618461	20.5183	7.4948	1322.6	139205
422	178084	75151448	20.5426	7.5007	1325.8	139867
423	178929	75686967	20.5670	7.5067	1328.9	140531
424	179776	76225024	20.5913	7.5126	1332.0	141196
425	180625	76765625	20.6155	7.5185	1335.2	141863
426	181476	77308776	20.6398	7.5244	1338.3	142531
427	182329	77854483	20.6640	7.5302	1341.5	143201
428	183184	78402752	20.6882	7.5361	1344.6	143872
429	184041	78953589	20.7123	7.5420	1347.7	144545
430	184900	79507000	20.7364	7.5478	1350.9	145220
431	185761	80062991	20.7605	7.5537	1354.0	145896
432	186624	80621568	20.7846	7.5595	1357.2	146574
433	187489	81182737	20.8087	7.5654	1360.3	147254
434	188356	81746504	20.8327	7.5712	1363.5	147934
435	189225	82312875	20.8567	7.5770	1366.6	148617
436	190096	82881856	20.8806	7.5828	1369.7	149301
437	190969	83453453	20.9045	7.5886	1372.9	149987
438	191844	84027672	20.9284	7.5944	1376.0	150674
439	192721	84604519	20.9523	7.6001	1379.2	151363
440	193600	85184000	20.9762	7.6059	1382.3	152053

SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, CIRCUMFERENCES AND CIRCULAR AREAS OF NOS. FROM 1 TO 520

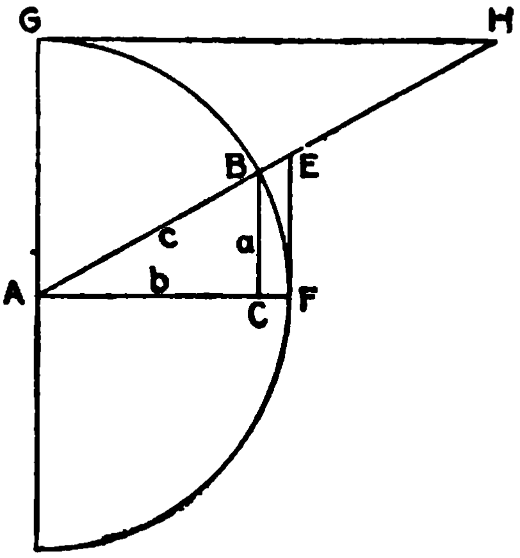
No.	Square	Cube	Sq. Root	Cube Root	Circle	
					Circum.	Area
441	194481	85766121	21.0000	7.6117	1385.4	152745
442	195364	86350888	21.0238	7.6174	1388.6	153439
443	196249	86938307	21.0476	7.6232	1391.7	154134
444	197136	87528384	21.0713	7.6289	1394.9	154830
445	198025	88121125	21.0950	7.6346	1398.0	155528
446	198916	88716536	21.1187	7.6403	1401.2	156228
447	199809	89314623	21.1424	7.6460	1404.3	156930
448	200704	89915392	21.1660	7.6517	1407.4	157633
449	201601	90518849	21.1896	7.6574	1410.6	158337
450	202500	91125000	21.2132	7.6631	1413.7	159043
451	203401	91733851	21.2368	7.6688	1416.9	159751
452	204304	92345408	21.2603	7.6744	1420.0	160460
453	205209	92959677	21.2838	7.6801	1423.1	161171
454	206116	93576664	21.3073	7.6857	1426.3	161883
455	207025	94196375	21.3307	7.6914	1429.4	162597
456	207936	94818816	21.3542	7.6970	1432.6	163313
457	208849	95443993	21.3776	7.7026	1435.7	164030
458	209764	96071912	21.4009	7.7082	1438.9	164748
459	210681	96702579	21.4243	7.7138	1442.0	165468
460	211600	97336000	21.4476	7.7194	1445.1	166190
461	212521	97972181	21.4709	7.7250	1448.3	166914
462	213444	98611128	21.4942	7.7306	1451.4	167639
463	214369	99252847	21.5174	7.7362	1454.6	168365
464	215296	99897344	21.5407	7.7418	1457.7	169093
465	216225	100544625	21.5639	7.7473	1460.8	169823
466	217156	101194696	21.5870	7.7529	1464.0	170554
467	218089	101847563	21.6102	7.7584	1467.1	171287
468	219024	102503232	21.6333	7.7639	1470.3	172021
469	219961	103161709	21.6564	7.7695	1473.4	172757
470	220900	103823000	21.6795	7.7750	1476.5	173494
471	221841	104487111	21.7025	7.7805	1479.7	174234
472	222784	105154048	21.7256	7.7860	1482.8	174974
473	223729	105823817	21.7486	7.7915	1486.0	175716
474	224676	106496424	21.7715	7.7970	1489.1	176460
475	225625	107171875	21.7945	7.8025	1492.3	177205
476	226576	107850176	21.8174	7.8079	1495.4	177952
477	227529	108531333	21.8403	7.8134	1498.5	178701
478	228484	109215352	21.8632	7.8188	1501.7	179451
479	229441	109902239	21.8861	7.8243	1504.8	180203
480	230400	110592000	21.9089	7.8297	1508.0	180956

SQUARES, CUBES, SQUARE ROOTS, CUBE ROOTS, CIRCUMFERENCES AND CIRCULAR AREAS OF NOS. FROM 1 TO 520

No.	Square	Cube	Sq. Root	Cube Root	Circle	
					Circum.	Area
481	231361	111284641	21.9317	7.8352	1511.1	181711
482	232324	111980168	21.9545	7.8406	1514.3	182467
483	233289	112678587	21.9773	7.8460	1517.4	183225
484	234256	113379904	22.0000	7.8514	1520.5	183984
485	235225	114084125	22.0227	7.8568	1523.7	184745
486	236196	114791256	22.0454	7.8622	1526.8	185508
487	237169	115501303	22.0681	7.8676	1530.0	186272
488	238144	116214272	22.0907	7.8730	1533.1	187038
489	239121	116930169	22.1133	7.8784	1536.2	187805
490	240100	117649000	22.1359	7.8837	1539.4	188574
491	241081	118370771	22.1585	7.8891	1542.5	189345
492	242064	119095488	22.1811	7.8944	1545.7	190117
493	243049	119823157	22.2036	7.8998	1548.8	190890
494	244036	120553784	22.2261	7.9051	1551.9	191665
495	245025	121287375	22.2486	7.9105	1555.1	192442
496	246016	122023936	22.2711	7.9158	1558.2	193221
497	247009	122763473	22.2935	7.9211	1561.4	194000
498	248004	123505992	22.3159	7.9264	1564.5	194782
499	249001	124251499	22.3383	7.9317	1567.7	195565
500	250000	125000000	22.3607	7.9370	1570.8	196350
501	251001	125751501	22.3830	7.9423	1573.9	197136
502	252004	126506008	22.4054	7.9476	1577.1	197923
503	253009	127263527	22.4277	7.9528	1580.2	198713
504	254016	128024064	22.4499	7.9581	1583.4	199504
505	255025	128787625	22.4722	7.9634	1586.5	200296
506	256036	129554216	22.4944	7.9686	1589.7	201090
507	257049	130323843	22.5167	7.9739	1592.8	201886
508	258064	131096512	22.5389	7.9791	1595.9	202683
509	259081	131872229	22.5610	7.9843	1599.1	203482
510	260100	132651000	22.5832	7.9896	1602.2	204282
511	261121	133432831	22.6053	7.9948	1605.4	205084
512	262144	134217728	22.6274	8.0000	1608.5	205887
513	263169	135005697	22.6495	8.0052	1611.6	206692
514	264196	135796744	22.6716	8.0104	1614.8	207499
515	265225	136590875	22.6936	8.0156	1617.9	208307
516	266256	137388096	22.7156	8.0208	1621.1	209117
517	267289	138188413	22.7376	8.0260	1624.2	209928
518	268324	138991832	22.7596	8.0311	1627.3	210741
519	269361	139798359	22.7816	8.0363	1630.5	211556
520	270400	140608000	22.8035	8.0415	1633.6	212372

TABLE 72. TRIGONOMETRIC FUNCTIONS AND THE SOLUTION OF TRIANGLES

In the accompanying figure the trigonometric functions of the angle A between the lines $B\ A$ and $A\ C$ are as follows;



$$\begin{aligned} \sin A &= B\,C \\ \cos A &= A\,C \\ \tan A &= E\,F \\ \cot A &= G\,H \\ \sec A &= A\,E \\ \operatorname{cosec} A &= A\,H \\ \text{ex-sec } A &= B\,E \end{aligned}$$

In the right-angled triangle $A\ B\ C$ let a equal the side $B\ C$ opposite the angle A; let b equal the side $A\ C$ opposite the angle B; let c equal $A\ B$, the side opposite the angle C.

Let $C = 90°$
The following formulæ apply to right-angled triangles:

Angles.

$$\begin{aligned} A + B + C &= 180° \\ A + B &= 90° \\ A &= 90° - B \\ B &= 90° - A \end{aligned}$$

$$\sin A = \frac{a}{c} \qquad \cos A = \frac{b}{c} \qquad \tan A = \frac{a}{b}$$

Area

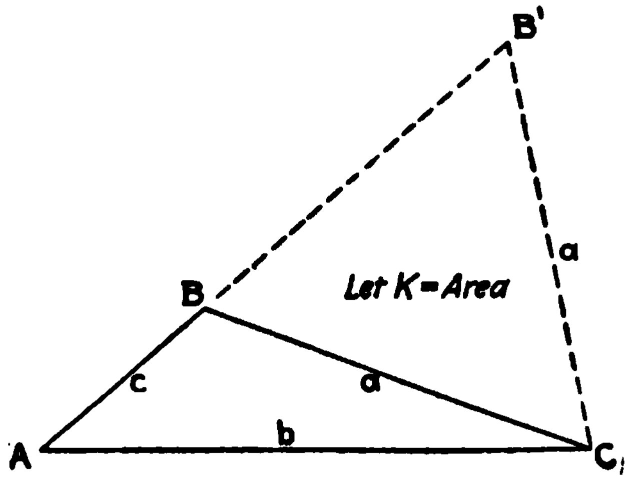
$$\text{area} = \frac{a\,b}{2}$$

Sides.

$$\begin{aligned} a &= c \sin A = b \tan A \\ a &= \sqrt{(c+b)\ (c-b)} \\ b &= c \cos. A = \frac{a}{\tan A} \\ b &= \sqrt{(c+a)\ (c-a)} \\ c &= \frac{a}{\sin A} = \frac{b}{\cos A} \\ c &= \sqrt{a^2 + b^2} \end{aligned}$$

Oblique Triangles.

Note. Where an angle is more than 90° its sine, cosine, and tangent are equal to that of the angle (180° – the angle in question); that is, if the sine of 120° is desired take the sine of (180° – 120°) = 60°.



Given	Desired	Formulæ
A, B, a	C, b	$C = 180 - (A + B)$; $b = \dfrac{a}{\sin A} \sin B$
	c, K	$c = \dfrac{a}{\sin A} \sin (A + B)$; $K = \dfrac{a^2 \sin B \sin C}{2 \sin A}$
A, a, b	B, C	$\sin B = \dfrac{\sin A}{a} b$; $C = 180° - (A + B)$
	c	$c = \dfrac{a}{\sin A} \sin C$
		Two solutions are possible with B′ as an acute angle and B as an obtuse angle
C, a, b	$\frac{1}{2}(A+B)$	$\frac{1}{2}(A+B) = 90° - \frac{1}{2} C$
	$\frac{1}{2}(A-B)$	$\tan \frac{1}{2}(A-B) = \dfrac{a-b}{a+b} \tan \frac{1}{2}(A+B)$
	$A\ B$	$A = \frac{1}{2}(A+B) + \frac{1}{2}(A-B)$ $B = \frac{1}{2}(A+B) - \frac{1}{2}(A-B)$
	c	$c = (a-b) \dfrac{\sin \frac{1}{2}(A+B)}{\sin \frac{1}{2}(A-B)}$
	K	$K = \frac{1}{2} ab \sin C$
a, b, c	B	In the following formula $s = \frac{1}{2}(a+b+c)$
		$\sin \frac{1}{2} B = \sqrt{\dfrac{(s-a)(s-c)}{ac}}$
		$\sin B = \dfrac{2\sqrt{s(s-a)(s-b)(s-c)}}{ac}$
	K	$K = \sqrt{s(s-a)(s-b)(s-c)}$

TABLE 73

	0°		1°		2°		3°		
′	TAN.	CO-TAN.	TAN.	CO-TAN.	TAN.	CO-TAN.	TAN.	CO-TAN.	′
0	.00000	Infinite.	.01746	57.2900	.03492	28.6363	.05241	19.0811	60
1	.00029	3437.750	.01775	56.3506	.03521	28.3994	.05270	18.9755	59
2	.00058	1718.870	.01804	55.4415	.03550	28.1664	.05299	18.8711	58
3	.00087	1145.920	.01833	54.5613	.03579	27.9372	.05328	18.7678	57
4	.00116	859.436	.01862	53.7086	.03609	27.7117	.05357	18.6656	56
5	.00145	687.549	.01891	52.8821	.03638	27.4899	.05387	18.5645	55
6	.00175	572.957	.01920	52.0807	.03667	27.2715	.05416	18.4645	54
7	.00204	491.106	.01949	51.3032	.03696	27.0566	.05445	18.3655	53
8	.00233	429.718	.01978	50.5485	.03725	26.8450	.05474	18.2677	52
9	.00262	381.971	.02007	49.8157	.03754	26.6367	.05503	18.1708	51
10	.00291	343.774	.02036	49.1039	.03783	26.4316	.05533	18.0750	50
11	.00320	312.521	.02066	48.4121	.03812	26.2296	.05562	17.9802	49
12	.00349	286.478	.02095	47.7395	.03842	26.0307	.05591	17.8863	48
13	.00378	264.441	.02124	47.0853	.03871	25.8348	.05620	17.7934	47
14	.00407	245.552	.02153	46.4489	.03900	25.6418	.05649	17.7015	46
15	.00436	229.182	.02182	45.8294	.03929	25.4517	.05678	17.6106	45
16	.00465	214.858	.02211	45.2261	.03958	25.2644	.05708	17.5205	44
17	.00495	202.219	.02240	44.6386	.03987	25.0798	.05737	17.4314	43
18	.00524	190.984	.02269	44.0661	.04016	24.8978	.05766	17.3432	42
19	.00553	180.932	.02298	43.5081	.04046	24.7185	.05795	17.2558	41
20	.00582	171.885	.02328	42.9641	.04075	24.5418	.05824	17.1693	40
21	.00611	163.700	.02357	42.4335	.04104	24.3675	.05854	17.0837	39
22	.00640	156.259	.02386	41.9158	.04133	24.1957	.05883	16.9990	38
23	.00669	149.465	.02415	41.4106	.04162	24.0263	.05912	16.9150	37
24	.00698	143.237	.02444	40.9174	.04191	23.8593	.05941	16.8319	36
25	.00727	137.507	.02473	40.4358	.04220	23.6945	.05970	16.7496	35
26	.00756	132.219	.02502	39.9655	.04250	23.5321	.05999	16.6681	34
27	.00785	127.321	.02531	39.5059	.04279	23.3718	.06029	16.5874	33
28	.00814	122.774	.02560	39.0568	.04308	23.2137	.06058	16.5075	32
29	.00844	118.540	.02589	38.6177	.04337	23.0577	.06087	16.4283	31
30	.00873	114.589	.02619	38.1885	.04366	22.9038	.06116	16.3499	30
31	.00902	110.892	.02648	37.7686	.04395	22.7519	.06145	16.2722	29
32	.00931	107.426	.02677	37.3579	.04424	22.6020	.06175	16.1952	28
33	.00960	104.171	.02706	36.9560	.04454	22.4541	.06204	16.1190	27
34	.00989	101.107	.02735	36.5627	.04483	22.3081	.06233	16.0435	26
35	.01018	98.2179	.02764	36.1776	.04512	22.1640	.06262	15.9687	25
36	.01047	95.4895	.02793	35.8006	.04541	22.0217	.06291	15.8945	24
37	.01076	92.9085	.02822	35.4313	.04570	21.8813	.06321	15.8211	23
38	.01105	90.4633	.02851	35.0695	.04599	21.7426	.06350	15.7483	22
39	.01135	88.1436	.02881	34.7151	.04628	21.6056	.06379	15.6762	21
40	.01164	85.9398	.02910	34.3678	.04658	21.4704	.06408	15.6048	20
41	.01193	83.8435	.02939	34.0273	.04687	21.3369	.06437	15.5340	19
42	.01222	81.8470	.02968	33.6935	.04716	21.2049	.06467	15.4638	18
43	.01251	79.9434	.02997	33.3662	.04745	21.0747	.06496	15.3943	17
44	.01280	78.1263	.03026	33.0452	.04774	20.9460	.06525	15.3254	16
45	.01309	76.3900	.03055	32.7303	.04803	20.8188	.06554	15.2571	15
46	.01338	74.7292	.03084	32.4213	.04832	20.6932	.06584	15.1893	14
47	.01367	73.1390	.03114	32.1181	.04862	20.5691	.06613	15.1222	13
48	.01396	71.6151	.03143	31.8205	.04891	20.4465	.06642	15.0557	12
49	.01425	70.1533	.03172	31.5284	.04920	20.3253	.06671	14.9898	11
50	.01455	68.7501	.03201	31.2416	.04949	20.2056	.06700	14.9244	10
51	.01484	67.4019	.03230	30.9599	.04978	20.0872	.06730	14.8596	9
52	.01513	66.1055	.03259	30.6833	.05007	19.9702	.06759	14.7954	8
53	.01542	64.8580	.03288	30.4116	.05037	19.8546	.06788	14.7317	7
54	.01571	63.6567	.03317	30.1446	.05066	19.7403	.06817	14.6685	6
55	.01600	62.4992	.03346	29.8823	.05095	19.6273	.06847	14.6059	5
56	.01629	61.3829	.03376	29.6245	.05124	19.5156	.06876	14.5438	4
57	.01658	60.3058	.03405	29.3711	.05153	19.4051	.06905	14.4823	3
58	.01687	59.2659	.03434	29.1220	.05182	19.2959	.06934	14.4212	2
59	.01716	58.2612	.03463	28.8771	.05212	19.1879	.06963	14.3607	1
60	.01746	57.2900	.03492	28.6363	.05241	19.0811	.06993	14.3007	0
′	CO-TAN.	TAN.	CO-TAN.	TAN.	CO-TAN.	TAN.	CO-TAN.	TAN.	′
	89°		88°		87°		86°		

′	4° Tan.	4° Co-tan.	5° Tan.	5° Co-tan.	6° Tan.	6° Co-tan.	7° Tan.	7° Co-tan.	′
0	.06993	14.3007	.08749	11.4301	.10510	9.51436	.12278	8.14435	60
1	.07022	14.2411	.08778	11.3919	.10540	9.48781	.12308	8.12481	59
2	.07051	14.1821	.08807	11.3540	.10569	9.46141	.12338	8.10536	58
3	.07080	14.1235	.08837	11.3163	.10599	9.43515	.12367	8.08600	57
4	.07110	14.0655	.08866	11.2789	.10628	9.40904	.12397	8.06674	56
5	.07139	14.0079	.08895	11.2417	.10657	9.38307	.12426	8.04756	55
6	.07168	13.9507	.08925	11.2048	.10687	9.35724	.12456	8.02848	54
7	.07197	13.8940	.08954	11.1681	.10716	9.33154	.12485	8.00948	53
8	.07227	13.8378	.08983	11.1316	.10746	9.30599	.12515	7.99058	52
9	.07256	13.7821	.09013	11.0954	.10775	9.28058	.12544	7.97176	51
10	.07285	13.7267	.09042	11.0594	.10805	9.25530	.12574	7.95302	50
11	.07314	13.6719	.09071	11.0237	.10834	9.23016	.12603	7.93438	49
12	.07344	13.6174	.09101	10.9882	.10863	9.20516	.12633	7.91582	48
13	.07373	13.5634	.09130	10.9529	.10893	9.18028	.12662	7.89734	47
14	.07402	13.5098	.09159	10.9178	.10922	9.15554	.12692	7.87895	46
15	.07431	13.4566	.09189	10.8829	.10952	9.13093	.12722	7.86064	45
16	.07461	13.4039	.09218	10.8483	.10981	9.10646	.12751	7.84242	44
17	.07490	13.3515	.09247	10.8139	.11011	9.08211	.12781	7.82428	43
18	.07519	13.2996	.09277	10.7797	.11040	9.05789	.12810	7.80622	42
19	.07548	13.2480	.09306	10.7457	.11070	9.03379	.12840	7.78825	41
20	.07578	13.1969	.09335	10.7119	.11099	9.00983	.12869	7.77035	40
21	.07607	13.1461	.09365	10.6783	.11128	8.98598	.12899	7.75254	39
22	.07636	13.0958	.09394	10.6450	.11158	8.96227	.12929	7.73480	38
23	.07665	13.0458	.09423	10.6118	.11187	8.93867	.12958	7.71715	37
24	.07695	12.9962	.09453	10.5789	.11217	8.91520	.12988	7.69957	36
25	.07724	12.9469	.09482	10.5462	.11246	8.89185	.13017	7.68208	35
26	.07753	12.8981	.09511	10.5136	.11276	8.86862	.13047	7.66466	34
27	.07782	12.8496	.09541	10.4813	.11305	8.84551	.13076	7.64732	33
28	.07812	12.8014	.09570	10.4491	.11335	8.82252	.13106	7.63005	32
29	.07841	12.7536	.09600	10.4172	.11364	8.79964	.13136	7.61287	31
30	.07870	12.7062	.09629	10.3854	.11394	8.77689	.13165	7.59575	30
31	.07899	12.6591	.09658	10.3538	.11423	8.75425	.13195	7.57872	29
32	.07929	12.6124	.09688	10.3224	.11452	8.73172	.13224	7.56176	28
33	.07958	12.5660	.09717	10.2913	.11482	8.70931	.13254	7.54487	27
34	.07987	12.5199	.09746	10.2602	.11511	8.68701	.13284	7.52806	26
35	.08017	12.4742	.09776	10.2294	.11541	8.66482	.13313	7.51132	25
36	.08046	12.4288	.09805	10.1988	.11570	8.64275	.13343	7.49465	24
37	.08075	12.3838	.09834	10.1683	.11600	8.62078	.13372	7.47806	23
38	.08104	12.3390	.09864	10.1381	.11629	8.59893	.13402	7.46154	22
39	.08134	12.2946	.09893	10.1080	.11659	8.57718	.13432	7.44509	21
40	.08163	12.2505	.09923	10.0780	.11688	8.55555	.13461	7.42871	20
41	.08192	12.2067	.09952	10.0483	.11718	8.53402	.13491	7.41240	19
42	.08221	12.1632	.09981	10.0187	.11747	8.51259	.13521	7.39616	18
43	.08251	12.1201	.10011	9.98931	.11777	8.49128	.13550	7.37999	17
44	.08280	12.0772	.10040	9.96007	.11806	8.47007	.13580	7.36389	16
45	.08309	12.0346	.10069	9.93101	.11836	8.44896	.13609	7.34786	15
46	.08339	11.9923	.10099	9.90211	.11865	8.42795	.13639	7.33190	14
47	.08368	11.9504	.10128	9.87338	.11895	8.40705	.13669	7.31600	13
48	.08397	11.9087	.10158	9.84482	.11924	8.38625	.13698	7.30018	12
49	.08427	11.8673	.10187	9.81641	.11954	8.36555	.13728	7.28442	11
50	.08456	11.8262	.10216	9.78817	.11983	8.34496	.13758	7.26873	10
51	.08485	11.7853	.10246	9.76009	.12013	8.32446	.13787	7.25310	9
52	.08514	11.7448	.10275	9.73217	.12042	8.30406	.13817	7.23754	8
53	.08544	11.7045	.10305	9.70441	.12072	8.28376	.13846	7.22204	7
54	.08573	11.6645	.10334	9.67680	.12101	8.26355	.13876	7.20661	6
55	.08602	11.6248	.10363	9.64935	.12131	8.24345	.13906	7.19125	5
56	.08632	11.5853	.10393	9.62205	.12160	8.22344	.13935	7.17594	4
57	.08661	11.5461	.10422	9.59490	.12190	8.20352	.13965	7.16071	3
58	.08690	11.5072	.10452	9.56791	.12219	8.18370	.13995	7.14553	2
59	.08720	11.4685	.10481	9.54106	.12249	8.16398	.14024	7.13042	1
60	.08749	11.4301	.10510	9.51436	.12278	8.14435	.14054	7.11537	0
′	Co-tan.	Tan.	Co-tan.	Tan.	Co-tan.	Tan.	Co-tan.	Tan.	′
	85°		84°		83°		82°		

′	8° Tan.	8° Co-tan.	9° Tan.	9° Co-tan.	10° Tan.	10° Co-tan.	11° Tan.	11° Co-tan.	′
0	.14054	7.11537	.15838	6.31375	.17633	5.67128	.19438	5.14455	60
1	.14084	7.10038	.15868	6.30189	.17663	5.66165	.19468	5.13658	59
2	.14113	7.08546	.15898	6.29007	.17693	5.65205	.19498	5.12862	58
3	.14143	7.07059	.15928	6.27829	.17723	5.64248	.19529	5.12069	57
4	.14173	7.05579	.15958	6.26655	.17753	5.63295	.19559	5.11279	56
5	.14202	7.04105	.15988	6.25486	.17783	5.62344	.19589	5.10490	55
6	.14232	7.02637	.16017	6.24321	.17813	5.61397	.19619	5.09704	54
7	.14262	7.01174	.16047	6.23160	.17843	5.60452	.19649	5.08921	53
8	.14291	6.99718	.16077	6.22003	.17873	5.59511	.19680	5.08139	52
9	.14321	6.98268	.16107	6.20851	.17903	5.58573	.19710	5.07360	51
10	.14351	6.96823	.16137	6.19703	.17933	5.57638	.19740	5.06584	50
11	.14381	6.95385	.16167	6.18559	.17963	5.56706	.19770	5.05809	49
12	.14410	6.93952	.16196	6.17419	.17993	5.55777	.19801	5.05037	48
13	.14440	6.92525	.16226	6.16283	.18023	5.54851	.19831	5.04267	47
14	.14470	6.91104	.16256	6.15151	.18053	5.53927	.19861	5.03499	46
15	.14499	6.89688	.16286	6.14023	.18083	5.53007	.19891	5.02734	45
16	.14529	6.88278	.16316	6.12899	.18113	5.52090	.19921	5.01971	44
17	.14559	6.86874	.16346	6.11779	.18143	5.51176	.19952	5.01210	43
18	.14588	6.85475	.16376	6.10664	.18173	5.50264	.19982	5.00451	42
19	.14618	6.84082	.16405	6.09552	.18203	5.49356	.20012	4.99695	41
20	.14648	6.82694	.16435	6.08444	.18233	5.48451	.20042	4.98940	40
21	.14678	6.81312	.16465	6.07340	.18263	5.47548	.20073	4.98188	39
22	.14707	6.79936	.16495	6.06240	.18293	5.46648	.20103	4.97438	38
23	.14737	6.78564	.16525	6.05143	.18323	5.45751	.20133	4.96690	37
24	.14767	6.77199	.16555	6.04051	.18353	5.44857	.20164	4.95945	36
25	.14796	6.75838	.16585	6.02962	.18383	5.43966	.20194	4.95201	35
26	.14826	6.74483	.16615	6.01878	.18414	5.43077	.20224	4.94460	34
27	.14856	6.73133	.16645	6.00797	.18444	5.42192	.20254	4.93721	33
28	.14886	6.71789	.16674	5.99720	.18474	5.41309	.20285	4.92984	32
29	.14915	6.70450	.16704	5.98646	.18504	5.40429	.20315	4.92249	31
30	.14945	6.69116	.16734	5.97576	.18534	5.39552	.20345	4.91516	30
31	.14975	6.67787	.16764	5.96510	.18564	5.38677	.20376	4.90785	29
32	.15005	6.66463	.16794	5.95448	.18594	5.37805	.20406	4.90056	28
33	.15034	6.65144	.16824	5.94390	.18624	5.36936	.20436	4.89330	27
34	.15064	6.63831	.16854	5.93335	.18654	5.36070	.20466	4.83605	26
35	.15094	6.62523	.16884	5.92283	.18684	5.35206	.20497	4.87882	25
36	.15124	6.61219	.16914	5.91235	.18714	5.34345	.20527	4.87162	24
37	.15153	6.59921	.16944	5.90191	.18745	5.33487	.20557	4.86444	23
38	.15183	6.58627	.16974	5.89151	.18775	5.32631	.20588	4.85727	22
39	.15213	6.57339	.17004	5.88114	.18805	5.31778	.20618	4.85013	21
40	.15243	6.56055	.17033	5.87080	.18835	5.30928	.20648	4.84300	20
41	.15272	6.54777	.17063	5.86051	.18865	5.30080	.20679	4.83590	19
42	.15302	6.53503	.17093	5.85024	.18895	5.29235	.20709	4.82882	18
43	.15332	6.52234	.17123	5.84001	.18925	5.28393	.20739	4.82175	17
44	.15362	6.50970	.17153	5.82982	.18955	5.27553	.20770	4.81471	16
45	.15391	6.49710	.17183	5.81966	.18986	5.26715	.20800	4.80769	15
46	.15421	6.48456	.17213	5.80953	.19016	5.25880	.20830	4.80068	14
47	.15451	6.47206	.17243	5.79944	.19046	5.25048	.20861	4.79370	13
48	.15481	6.45961	.17273	5.78938	.19076	5.24218	.20891	4.78673	12
49	.15511	6.44720	.17303	5.77936	.19106	5.23391	.20921	4.77978	11
50	.15540	6.43484	.17333	5.76937	.19136	5.22566	.20952	4.77286	10
51	.15570	6.42253	.17363	5.75941	.19166	5.21744	.20982	4.76595	9
52	.15600	6.41026	.17393	5.74949	.19197	5.20925	.21013	4.75906	8
53	.15630	6.39804	.17423	5.73960	.19227	5.20107	.21043	4.75219	7
54	.15660	6.38587	.17453	5.72974	.19257	5.19293	.21073	4.74534	6
55	.15689	6.37374	.17483	5.71992	.19287	5.18480	.21104	4.73851	5
56	.15719	6.36165	.17513	5.71013	.19317	5.17671	.21134	4.73170	4
57	.15749	6.34961	.17543	5.70037	.19347	5.16863	.21164	4.72490	3
58	.15779	6.33761	.17573	5.69064	.19378	5.16058	.21195	4.71813	2
59	.15809	6.32566	.17603	5.68094	.19408	5.15256	.21225	4.71137	1
60	.15838	6.31375	.17633	5.67128	.19438	5.14455	.21256	4.70463	0
′	81° Co-tan.	81° Tan.	80° Co-tan.	80° Tan.	79° Co-tan.	79° Tan.	78° Co-tan.	78° Tan.	′

	28°		29°		30°		31°		
′	Tan.	Co-tan.	Tan.	Co-tan.	Tan.	Co-tan.	Tan.	Co-tan.	
0	.53171	1.88073	.55431	1.80405	.57735	1.73205	.60086	1.66428	60
1	.53208	1.87941	.55469	1.80281	.57774	1.73089	.60126	1.66318	59
2	.53246	1.87809	.55507	1.80158	.57813	1.72973	.60165	1.66209	58
3	.53283	1.87677	.55545	1.80034	.57851	1.72857	.60205	1.66099	57
4	.53320	1.87546	.55583	1.79911	.57890	1.72741	.60245	1.65990	56
5	.53358	1.87415	.55621	1.79788	.57929	1.72625	.60284	1.65881	55
6	.53395	1.87283	.55659	1.79665	.57968	1.72509	.60324	1.65772	54
7	.53432	1.87152	.55697	1.79542	.58007	1.72393	.60364	1.65663	53
8	.53470	1.87021	.55736	1.79419	.58046	1.72278	.60403	1.65554	52
9	.53507	1.86891	.55774	1.79296	.58085	1.72163	.60443	1.65445	51
10	.53545	1.86760	.55812	1.79174	.58124	1.72047	.60483	1.65337	50
11	.53582	[illegible]	.55850	1.79051	.58162	1.71932	.60522	[illegible]	49
12	.53620	[illegible]	.55888	1.78929	.58201	1.71817	.60562	[illegible]	48
13	.53657	[illegible]	.55926	1.78807	.58240	1.71702	.60602	[illegible]	47
14	.53694	[illegible]	.55964	1.78685	.58279	1.71588	.60642	[illegible]	46
15	.53732	[illegible]	.56003	1.78563	.58318	1.71473	.60681	[illegible]	45
16	.53769	[illegible]	.56041	1.78441	.58357	1.71358	.60721	[illegible]	44
17	.53807	[illegible]	.56079	1.78319	.58396	1.71244	.60761	[illegible]	43
18	.53844	[illegible]	.56117	1.78198	.58435	1.71129	.60801	[illegible]	42
19	.53882	[illegible]	.56156	1.78077	.58474	1.71015	.60841	[illegible]	41
20	.53920	[illegible]	.56194	1.77955	.58513	1.70901	.60881	[illegible]	40
21	.53957	1.85333	.56232	1.77834	.58552	1.70787	.60921	1.64148	39
22	.53995	1.85204	.56270	1.77713	.58591	1.70673	.60960	1.64041	38
23	.54032	1.85075	.56309	1.77592	.58631	1.70560	.61000	1.63934	37
24	.54070	1.84946	.56347	1.77471	.58670	1.70446	.61040	1.63826	36
25	.54107	1.84818	.56385	1.77351	.58709	1.70332	.61080	1.63719	35
26	.54145	1.84689	.56424	1.77230	.58748	1.70219	.61120	1.63612	34
27	.54183	1.84561	.56462	1.77110	.58787	1.70106	.61160	1.63505	33
28	.54220	1.84433	.56501	1.76990	.58826	1.69992	.61200	1.63398	32
29	.54258	1.84305	.56539	1.76869	.58865	1.69879	.61240	1.63292	31
30	.54296	1.84177	.56577	1.76749	.58905	1.69766	.61280	1.63185	30
31	.54333	1.84049	.56616	1.76630	.58944	1.69653	.61320	1.63079	29
32	.54371	1.83922	.56654	1.76510	.58983	1.69541	.61360	1.62972	28
33	.54409	1.83794	.56693	1.76390	.59022	1.69428	.61400	1.62866	27
34	.54446	1.83667	.56731	1.76271	.59061	1.69316	.61440	1.62760	26
35	.54484	1.83540	.56769	1.76151	.59101	1.69203	.61480	1.62654	25
36	.54522	1.83413	.56808	1.76032	.59140	1.69091	.61520	1.62548	24
37	.54560	1.83286	.56846	1.75913	.59179	1.68979	.61561	1.62442	23
38	.54597	1.83159	.56885	1.75794	.59218	1.68866	.61601	1.62336	22
39	.54635	1.83033	.56923	1.75675	.59258	1.68754	.61641	1.62230	21
40	.54673	1.82906	.56962	1.75556	.59297	1.68643	.61681	1.62125	20
41	.54711	1.82780	.57000	1.75437	.59336	1.68531	.61721	1.62019	19
42	.54748	1.82654	.57039	1.75319	.59376	1.68419	.61761	1.61914	18
43	.54786	1.82528	.57078	1.75200	.59415	1.68308	.61801	1.61808	17
44	.54824	1.82402	.57116	1.75082	.59454	1.68196	.61842	1.61703	16
45	.54862	1.82276	.57155	1.74964	.59494	1.68085	.61882	1.61598	15
46	.54900	1.82150	.57193	1.74846	.59533	1.67974	.61922	1.61493	14
47	.54938	1.82025	.57232	1.74728	.59573	1.67863	.61962	1.61388	13
48	.54975	1.81899	.57271	1.74610	.59612	1.67752	.62003	1.61283	12
49	.55013	1.81774	.57309	1.74492	.59651	1.67641	.62043	1.61179	11
50	.55051	1.81649	.57348	1.74375	.59691	1.67530	.62083	1.61074	10
51	.55089	1.81524	.57386	1.74257	.59730	1.67419	.62124	1.60970	9
52	.55127	1.81399	.57425	1.74140	.59770	1.67309	.62164	1.60865	8
53	.55165	1.81274	.57464	1.74022	.59809	1.67198	.62204	1.60761	7
54	.55203	1.81150	.57503	1.73905	.59849	1.67088	.62245	1.60657	6
55	.55241	1.81025	.57541	1.73788	.59888	1.66978	.62285	1.60553	5
56	.55279	1.80901	.57580	1.73671	.59928	1.66867	.62325	1.60449	4
57	.55317	1.80777	.57619	1.73555	.59967	1.66757	.62366	1.60345	3
58	.55355	1.80653	.57657	1.73438	.60007	1.66647	.62406	1.60241	2
59	.55393	1.80529	.57696	1.73321	.60046	1.66538	.62446	1.60137	1
60	.55431	1.80405	.57735	1.73205	.60086	1.66428	.62487	1.60033	0
	Co-tan.	Tan.	Co-tan.	Tan.	Co-tan.	Tan.	Co-tan.	Tan.	′
	61°		60°		59°		58°		

′	32°		33°		34°		35°		′
	Tan.	Co-tan.	Tan.	Co-tan.	Tan.	Co-tan.	Tan.	Co-tan.	
0	.62487	1.60033	.64941	1.53986	.67451	1.48256	.70021	1.42815	60
1	.62527	1.59930	.64982	1.53888	.67493	1.48163	.70064	1.42726	59
2	.62568	1.59826	.65024	1.53791	.67536	1.48070	.70107	1.42638	58
3	.62608	1.59723	.65065	1.53693	.67578	1.47977	.70151	1.42550	57
4	.62649	1.59620	.65106	1.53595	.67620	1.47885	.70194	1.42462	56
5	.62689	1.59517	.65148	1.53497	.67663	1.47792	.70238	1.42374	55
6	.62730	1.59414	.65189	1.53400	.67705	1.47699	.70281	1.42286	54
7	.62770	1.59311	.65231	1.53302	.67748	1.47607	.70325	1.42198	53
8	.62811	1.59208	.65272	1.53205	.67790	1.47514	.70368	1.42110	52
9	.62852	1.59105	.65314	1.53107	.67832	1.47422	.70412	1.42022	51
10	.62892	1.59002	.65355	1.53010	.67875	1.47330	.70455	1.41934	50
11	.62933	[illegible]	.65397	1.52913	.67917	1.47238	.70499	1.41847	49
12	.62973	[illegible]	.65438	1.52816	.67960	1.47146	.70542	1.41759	48
13	.63014	[illegible]	.65480	1.52719	.68002	1.47053	.70586	1.41672	47
14	.63055	[illegible]	.65521	1.52622	.68045	1.46962	.70629	1.41584	46
15	.63095	[illegible]	.65563	1.52525	.68088	1.46870	.70673	1.41497	45
16	.63136	[illegible]	.65604	1.52429	.68130	1.46778	.70717	1.41409	44
17	.63177	[illegible]	.65646	1.52332	.68173	1.46686	.70760	1.41322	43
18	.63217	[illegible]	.65688	1.52235	.68215	1.46595	.70804	1.41235	42
19	.63258	[illegible]	.65729	1.52139	.68258	1.46503	.70848	1.41148	41
20	.63299	[illegible]	.65771	1.52043	.68301	1.46411	.70891	1.41061	40
21	.63340	1.57879	.65813	1.51946	.68343	1.46320	.70935	1.40974	39
22	.63380	1.57778	.65854	1.51850	.68386	1.46229	.70979	1.40887	38
23	.63421	1.57676	.65896	1.51754	.68429	1.46137	.71023	1.40800	37
24	.63462	1.57575	.65938	1.51658	.68471	1.46046	.71066	1.40714	36
25	.63503	1.57474	.65980	1.51562	.68514	1.45955	.71110	1.40627	35
26	.63544	1.57372	.66021	1.51466	.68557	1.45864	.71154	1.40540	34
27	.63584	1.57271	.66063	1.51370	.68600	1.45773	.71198	1.40454	33
28	.63625	1.57170	.66105	1.51275	.68642	1.45682	.71242	1.40367	32
29	.63666	1.57069	.66147	1.51179	.68685	1.45592	.71285	1.40281	31
30	.63707	1.56969	.66189	1.51084	.68728	1.45501	.71329	1.40195	30
31	.63748	[illegible]	.66230	1.50988	.68771	1.45410	.71373	1.40109	29
32	.63789	[illegible]	.66272	1.50893	.68814	1.45320	.71417	1.40022	28
33	.63830	[illegible]	.66314	1.50797	.68857	1.45229	.71461	1.39936	27
34	.63871	[illegible]	.66356	1.50702	.68900	1.45139	.71505	1.39850	26
35	.63912	[illegible]	.66398	1.50607	.68942	1.45049	.71549	1.39764	25
36	.63953	[illegible]	.66440	1.50512	.68985	1.44958	.71593	1.39679	24
37	.63994	[illegible]	.66482	1.50417	.69028	1.44868	.71637	1.39593	23
38	.64035	[illegible]	.66524	1.50322	.69071	1.44778	.71681	1.39507	22
39	.64076	[illegible]	.66566	1.50228	.69114	1.44688	.71725	1.39421	21
40	.64117	[illegible]	.66608	1.50133	.69157	1.44598	.71769	1.39336	20
41	.64158	1.55866	.66650	1.50038	.69200	1.44508	.71813	1.39250	19
42	.64199	1.55766	.66692	1.49944	.69243	1.44418	.71857	1.39165	18
43	.64240	1.55666	.66734	1.49849	.69286	1.44329	.71901	1.39079	17
44	.64281	1.55567	.66776	1.49755	.69329	1.44239	.71946	1.38994	16
45	.64322	1.55467	.66818	1.49661	.69372	1.44149	.71990	1.38909	15
46	.64363	1.55368	.66860	1.49566	.69416	1.44060	.72034	1.38824	14
47	.64404	1.55269	.66902	1.49472	.69459	1.43970	.72078	1.38738	13
48	.64446	1.55170	.66944	1.49378	.69502	1.43881	.72122	1.38653	12
49	.64487	1.55071	.66986	1.49284	.69545	1.43792	.72167	1.38568	11
50	.64528	1.54972	.67028	1.49190	.69588	1.43703	.72211	1.38484	10
51	.64569	1.54873	.67071	1.49097	[illegible]	1.43614	.72255	1.38399	9
52	.64610	1.54774	.67113	1.49003	[illegible]	1.43525	.72299	1.38314	8
53	.64652	1.54675	.67155	1.48909	[illegible]	1.43436	.72344	1.38229	7
54	.64693	1.54576	.67197	1.48816	[illegible]	1.43347	.72388	1.38145	6
55	.64734	1.54478	.67239	1.48722	[illegible]	1.43258	.72432	1.38060	5
56	.64775	1.54379	.67282	1.48629	[illegible]	1.43169	.72477	1.37976	4
57	.64817	1.54281	.67324	1.48536	[illegible]	1.43080	.72521	1.37891	3
58	.64858	1.54183	.67366	1.48442	[illegible]	1.42992	.72565	1.37807	2
59	.64899	1.54085	.67409	1.48349	[illegible]	1.42903	.72610	1.37722	1
60	.64941	1.53986	.67451	1.48256	[illegible]	1.42815	.72654	1.37638	0
′	Co-tan.	Tan.	Co-tan.	Tan.	Co-tan.	Tan.	Co-tan.	Tan.	′
	57°		56°		55°		54°		

′	36° Tan.	36° Co-tan.	37° Tan.	37° Co-tan.	38° Tan.	38° Co-tan.	39° Tan.	39° Co-tan.	′
0	.72654	1.37638	.75355	1.32704	.78129	1.27994	.80978	1.23490	60
1	72699	1.37554	75401	1.32624	78175	1.27917	81027	1.23416	59
2	72743	1.37470	.75447	1.32544	78222	1.27841	81075	1.23343	58
3	72788	1.37386	75492	1.32464	78269	1.27764	81123	1.23270	57
4	72832	1.37302	75538	1.32384	.78316	1.27688	81171	1.23196	56
5	.72877	1.37218	75584	1.32304	78363	1.27611	81220	1.23123	55
6	72921	1.37134	75629	1.32224	78410	1.27535	81268	1.23050	54
7	72966	1.37050	75675	1.32144	.78457	1.27458	81316	1.22977	53
8	73010	1.36967	75721	1.32064	78504	1.27382	81364	1.22904	52
9	73055	1.36883	75767	1.31984	78551	1.27306	81413	1.22831	51
10	73100	1.36800	75812	1.31904	78598	1.27230	81461	1.22758	50
11	73144	1.[illegible]16	75858	1.31825	.78645	1.27153	81510	1.22685	49
12	73189	1.[illegible]33	75904	1.31745	78692	1.27077	81558	1.22612	48
13	73234	1.[illegible]49	75950	1.31666	78739	1.27001	81606	1.22539	47
14	73278	1.[illegible]66	75996	1.31586	78786	1.26925	81655	1.22467	46
15	73323	1.[illegible]83	76042	1.31507	78834	1.26849	81703	1.22394	45
16	73368	1.[illegible]00	76088	1.31427	78881	1.26774	81752	1.22321	44
17	73413	1.[illegible]17	76134	1.31348	78928	1.26698	81800	1.22249	43
18	73457	1.[illegible]33	76180	1.31269	78975	1.26622	81849	1.22176	42
19	73502	1.[illegible]51	76226	1.31190	79022	1.26546	81898	1.22104	41
20	73547	1.[illegible]68	76272	1.31110	79070	1.26471	81946	1.22031	40
21	73592	1.35885	76318	1.31031	79117	1.26395	81995	1.21959	39
22	73637	1.35802	76364	1.30952	79164	1.26319	82044	1.21886	38
23	73681	1.35719	76410	1.30873	79212	1.26244	82092	1.21814	37
24	73726	1.35637	76456	1.30795	79259	1.26169	82141	1.21742	36
25	73771	1.35554	76502	1.30716	79306	1.26093	82190	1.21670	35
26	73816	1.35472	.76548	1.30637	79354	1.26018	82238	1.21598	34
27	73861	1.35389	76594	1.30558	79401	1.25943	82287	1.21526	33
28	73906	1.35307	76640	1.30480	79449	1.25867	82336	1.21454	32
29	73951	1.35224	.76686	1.30401	79496	1.25792	82385	1.21382	31
30	73996	1.35142	76733	1.30323	79544	1.25717	82434	1.21310	30
31	74041	1.35060	76779	1.30244	79591	1.25642	82483	1.21238	29
32	74086	1.34978	76825	1.30166	79639	1.25567	82531	1.21166	28
33	74131	1.34896	76871	1.30087	79686	1.25492	82580	1.21094	27
34	74176	1.34814	76918	1.30009	79734	1.25417	82629	1.21023	26
35	74221	1.34732	.76964	1.29931	.79781	1.25343	82678	1.20951	25
36	74267	1.34650	77010	1.29853	79829	1.25268	82727	1.20879	24
37	74312	1.34568	77057	1.29775	79877	1.25193	82776	1.20808	23
38	74357	1.34487	77103	1.29696	79924	1.25118	82825	1.20736	22
39	74402	1.34405	77149	1.29618	79972	1.25044	82874	1.20665	21
40	74447	1.34323	77196	1.29541	80020	1.24969	82923	1.20593	20
41	74492	1.34242	77242	1.29463	80067	1.24895	82972	1.20522	19
42	74538	1.34160	77289	1.29385	80115	1.24820	83022	1.20451	18
43	74583	1.34079	.77335	1.29307	80163	1.24746	83071	1.20379	17
44	74628	1.33998	77382	1.29229	80211	1.24672	83120	1.20308	16
45	74674	1.33916	77428	1.29152	80258	1.24597	83169	1.20237	15
46	74719	1.33835	77475	1.29074	80306	1.24523	83218	1.20166	14
47	74764	1.33754	77521	1.28997	80354	1.24449	83268	1.20095	13
48	74810	1.33673	77568	1.28919	80402	1.24375	83317	1.20024	12
49	74855	1.33592	.77615	1.28842	80450	1.24301	83366	1.19953	11
50	74900	1.33511	.77661	1.28764	80498	1.24227	83415	1.19882	10
51	74946	1.33430	77708	1.28687	80546	1.24153	83465	1.19811	9
52	74991	1.33349	77754	1.28610	80594	1.24079	83514	1.19740	8
53	75037	1.33268	77801	1.28533	80642	1.24005	83564	1.19669	7
54	75082	1.33187	.77848	1.28456	80690	1.23931	83613	1.19599	6
55	75128	1.33107	77895	1.28379	80738	1.23858	83662	1.19528	5
56	75173	1.33026	77941	1.28302	80786	1.23784	83712	1.19457	4
57	75219	1.32946	77988	1.28225	80834	1.23710	83761	1.19387	3
58	75264	1.32865	78035	1.28148	80882	1.23637	83811	1.19316	2
59	75310	1.32785	78082	1.28071	80930	1.23563	83860	1.19246	1
60	75355	1.32704	.78129	1.27994	80978	1.23490	83910	1.19175	0
	Co-tan.	Tan.	Co-tan.	Tan.	Co-tan.	Tan.	Co-tan.	Tan.	′
	53°		52°		51°		50°		

′	40° Tan.	40° Co-tan.	41° Tan.	41° Co-tan.	42° Tan.	42° Co-tan.	43° Tan.	43° Co-tan.	′
0	.83910	1.19175	.86929	1.15037	.90040	1.11061	.93252	1.07237	60
1	.83960	1.19105	.86980	1.14969	.90093	1.10996	.93306	1.07174	59
2	.84009	1.19035	.87031	1.14902	.90146	1.10931	.93360	1.07112	58
3	.84059	1.18964	.87082	1.14834	.90199	1.10867	.93415	1.07049	57
4	.84108	1.18894	.87133	1.14767	.90251	1.10802	.93469	1.06987	56
5	.84158	1.18824	.87184	1.14699	.90304	1.10737	.93524	1.06925	55
6	.84208	1.18754	.87236	1.14632	.90357	1.10672	.93578	1.06862	54
7	.84258	1.18684	.87287	1.14565	.90410	1.10607	.93633	1.06800	53
8	.84307	1.18614	.87338	1.14498	.90463	1.10543	.93688	1.06738	52
9	.84357	1.18544	.87389	1.14430	.90516	1.10478	.93742	1.06676	51
10	.84407	1.18474	.87441	1.14363	.90569	1.10414	.93797	1.06613	50
11	.84457	[illegible]	.87492	1.14296	.90621	1.10349	.93852	1.06551	49
12	.84507	[illegible]	.87543	1.14229	.90674	1.10285	.93906	1.06489	48
13	.84556	[illegible]	.87595	1.14162	.90727	1.10220	.93961	1.06427	47
14	.84606	[illegible]	.87646	1.14095	.90781	1.10156	.94016	1.06365	46
15	.84656	[illegible]	.87698	1.14028	.90834	1.10091	.94071	1.06303	45
16	.84706	[illegible]	.87749	1.13961	.90887	1.10027	.94125	1.06241	44
17	.84756	[illegible]	.87801	1.13894	.90940	1.09963	.94180	1.06179	43
18	.84806	[illegible]	.87852	1.13828	.90993	1.09899	.94235	1.06117	42
19	.84856	[illegible]	.87904	1.13761	.91046	1.09834	.94290	1.06056	41
20	.84906	1.17777	.87955	1.13694	.91099	1.09770	.94345	1.05994	40
21	.84956	1.17708	.88007	1.13627	.91153	1.09706	.94400	1.05932	39
22	.85006	1.17638	.88059	1.13561	.91206	1.09642	.94455	1.05870	38
23	.85057	1.17569	.88110	1.13494	.91259	1.09578	.94510	1.05809	37
24	.85107	1.17500	.88162	1.13428	.91313	1.09514	.94565	1.05747	36
25	.85157	1.17430	.88214	1.13361	.91366	1.09450	.94620	1.05685	35
26	.85207	1.17361	.88265	1.13295	.91419	1.09386	.94676	1.05624	34
27	.85257	1.17292	.88317	1.13228	.91473	1.09322	.94731	1.05562	33
28	.85308	1.17223	.88369	1.13162	.91526	1.09258	.94786	1.05501	32
29	.85358	1.17154	.88421	1.13096	.91580	1.09195	.94841	1.05439	31
30	.85408	1.17085	.88473	1.13029	.91633	1.09131	.94896	1.05378	30
31	[illegible]	[illegible]	.88524	1.12963	.91687	1.09067	.94952	1.05317	29
32	[illegible]	[illegible]	.88576	1.12897	.91740	1.09003	.95007	1.05255	28
33	[illegible]	[illegible]	.88628	1.12831	.91794	1.08940	.95062	1.05194	27
34	[illegible]	[illegible]	.88680	1.12765	.91847	1.08876	.95118	1.05133	26
35	[illegible]	[illegible]	.88732	1.12699	.91901	1.08813	.95173	1.05072	25
36	[illegible]	[illegible]	.88784	1.12633	.91955	1.08749	.95229	1.05010	24
37	[illegible]	[illegible]	.88836	1.12567	.92008	1.08686	.95284	1.04949	23
38	[illegible]	[illegible]	.88888	1.12501	.92062	1.08622	.95340	1.04888	22
39	[illegible]	[illegible]	.88940	1.12435	.92116	1.08559	.95395	1.04827	21
40	[illegible]	[illegible]	.88992	1.12369	.92170	1.08496	.95451	1.04766	20
41	.85963	1.16329	.89045	1.12303	.92224	1.08432	.95506	1.04705	19
42	.86014	1.16261	.89097	1.12238	.92277	1.08369	.95562	1.04644	18
43	.86064	1.16192	.89149	1.12172	.92331	1.08306	.95618	1.04583	17
44	.86115	1.16124	.89201	1.12106	.92385	1.08243	.95673	1.04522	16
45	.86166	1.16056	.89253	1.12041	.92439	1.08179	.95729	1.04461	15
46	.86216	1.15987	.89306	1.11975	.92493	1.08116	.95785	1.04401	14
47	.86267	1.15919	.89358	1.11909	.92547	1.08053	.95841	1.04340	13
48	.86318	1.15851	.89410	1.11844	.92601	1.07990	.95897	1.04279	12
49	.86368	1.15783	.89463	1.11778	.92655	1.07927	.95952	1.04218	11
50	.86419	1.15715	.89515	1.11713	.92709	1.07864	.96008	1.04158	10
51	.86470	1.15647	.89567	1.11648	.92763	1.07801	.96064	1.04097	9
52	.86521	1.15579	.89620	1.11582	.92817	1.07738	.96120	1.04036	8
53	.86572	1.15511	.89672	1.11517	.92872	1.07676	.96176	1.03976	7
54	.86623	1.15443	.89725	1.11452	.92926	1.07613	.96232	1.03915	6
55	.86674	1.15375	.89777	1.11387	.92980	1.07550	.96288	1.03855	5
56	.86725	1.15308	.89830	1.11321	.93034	1.07487	.96344	1.03794	4
57	.86776	1.15240	.89883	1.11256	.93088	1.07425	.96400	1.03734	3
58	.86827	1.15172	.89935	1.11191	.93143	1.07362	.96457	1.03674	2
59	.86878	1.15104	.89988	1.11126	.93197	1.07299	.96513	1.03613	1
60	.86929	1.15037	.90040	1.11061	.93252	1.07237	.96569	1.03553	0
′	49° Co-tan.	49° Tan.	48° Co-tan.	48° Tan.	47° Co-tan.	47° Tan.	46° Co-tan.	46° Tan.	′

	44°				44°				44°		
′	Tan.	Co-tan.	′	′	Tan.	Co-tan.	′	′	Tan.	Co-tan.	′
0	.96569	1.03553	60	21	.97756	1.02295	39	41	.98901	1.01112	19
1	.96625	1.03493	59	22	.97813	1.02236	38	42	.98958	1.01053	18
2	.96681	1.03433	58	23	.97870	1.02176	37	43	.99016	1.00994	17
3	.96738	1.03372	57	24	.97927	1.02117	36	44	.99073	1.00935	16
4	.96794	1.03312	56	25	.97984	1.02057	35	45	.99131	1.00876	15
5	.96850	1.03252	55	26	.98041	1.01998	34	46	.99189	1.00818	14
6	.96907	1.03192	54	27	.98098	1.01939	33	47	.99247	1.00759	13
7	.96963	1.03132	53	28	.98155	1.01879	32	48	.99304	1.00701	12
8	.97020	1.03072	52	29	.98213	1.01820	31	49	.99362	1.00642	11
9	.97076	1.03012	51	30	.98270	1.01761	30	50	.99420	1.00583	10
10	.97133	1.02952	50	31	.98327	1.01702	29	51	.99478	1.00525	9
11	.97189	1.02892	49	32	.98384	1.01642	28	52	.99536	1.00467	8
12	.97246	1.02832	48	33	.98441	1.01583	27	53	.99594	1.00408	7
13	.97302	1.02772	47	34	.98499	1.01524	26	54	.99652	1.00350	6
14	.97359	1.02713	46	35	.98556	1.01465	25	55	.99710	1.00291	5
15	.97416	1.02653	45	36	.98613	1.01406	24	56	.99768	1.00233	4
16	.97472	1.02593	44	37	.98671	1.01347	23	57	.99826	1.00175	3
17	.97529	1.02533	43	38	.98728	1.01288	22	58	.99884	1.00116	2
18	.97586	1.02474	42	39	.98786	1.01229	21	59	.99942	1.00058	1
19	.97643	1.02414	41	40	.98843	1.01170	20	60	1	1	0
20	.97700	1.02355	40								
′	Co-tan.	Tan.	′	′	Co-tan.	Tan.	′	′	Co-tan.	Tan.	′
	45°				45°				45°		

NATURAL SINES AND COSINES

	0°				0°				0°		
′	Sine	Cosine	′	′	Sine	Cosine	′	′	Sine	Cosine	′
0	.00000	1	60	21	.00611	.99998	39	41	.01193	.99993	19
1	.00029	1	59	22	.00640	.99998	38	42	.01222	.99993	18
2	.00058	1	58	23	.00669	.99998	37	43	.01251	.99992	17
3	.00087	1	57	24	.00698	.99998	36	44	.01280	.99992	16
4	.00116	1	56	25	.00727	.99997	35	45	.01309	.99991	15
5	.00145	1	55	26	.00756	.99997	34	46	.01338	.99991	14
6	.00175	1	54	27	.00785	.99997	33	47	.01367	.99991	13
7	.00204	1	53	28	.00814	.99997	32	48	.01396	.99990	12
8	.00233	1	52	29	.00844	.99996	31	49	.01425	.99990	11
9	.00262	1	51	30	.00873	.99996	30	50	.01454	.99989	10
10	.00291	1	50	31	.00902	.99996	29	51	.01483	.99989	9
11	.00320	.99999	49	32	.00931	.99996	28	52	.01513	.99989	8
12	.00349	.99999	48	33	.00960	.99995	27	53	.01542	.99988	7
13	.00378	.99999	47	34	.00989	.99995	26	54	.01571	.99988	6
14	.00407	.99999	46	35	.01018	.99995	25	55	.01600	.99987	5
15	.00436	.99999	45	36	.01047	.99995	24	56	.01629	.99987	4
16	.00465	.99999	44	37	.01076	.99994	23	57	.01658	.99986	3
17	.00495	.99999	43	38	.01105	.99994	22	58	.01687	.99986	2
18	.00524	.99999	42	39	.01134	.99994	21	59	.01716	.99985	1
19	.00553	.99998	41	40	.01164	.99993	20	60	.01745	.99985	0
20	.00582	.99998	40								
′	Cosine	Sine	′	′	Cosine	Sine	′	′	Cosine	Sine	′
	89°				89°				89°		

	1°		2°		3°		4°		
′	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	′
0	.01745	.99985	.03490	.99939	.05234	.99863	.06976	.99756	60
1	.01774	.99984	.03519	.99938	.05263	.99861	.07005	.99754	59
2	.01803	.99984	.03548	.99937	.05292	.99860	.07034	.99752	58
3	.01832	.99983	.03577	.99936	.05321	.99858	.07063	.99750	57
4	.01862	.99983	.03606	.99935	.05350	.99857	.07092	.99748	56
5	.01891	.99982	.03635	.99934	.05379	.99855	.07121	.99746	55
6	.01920	.99982	.03664	.99933	.05408	.99854	.07150	.99744	54
7	.01949	.99981	.03693	.99932	.05437	.99852	.07179	.99742	53
8	.01978	.99980	.03723	.99931	.05466	.99851	.07208	.99740	52
9	.02007	.99980	.03752	.99930	.05495	.99849	.07237	.99738	51
10	.02036	.99979	.03781	.99929	.05524	.99847	.07266	.99736	50
11	.02065	.99979	.03810	.99927	.05553	.99846	.07295	.99734	49
12	.02094	.99978	.03839	.99926	.05582	.99844	.07324	.99731	48
13	.02123	.99977	.03868	.99925	.05611	.99842	.07353	.99729	47
14	.02152	.99977	.03897	.99924	.05640	.99841	.07382	.99727	46
15	.02181	.99976	.03926	.99923	.05669	.99839	.07411	.99725	45
16	.02211	.99976	.03955	.99922	.05698	.99838	.07440	.99723	44
17	.02240	.99975	.03984	.99921	.05727	.99836	.07469	.99721	43
18	.02269	.99974	.04013	.99919	.05756	.99834	.07498	.99719	42
19	.02298	.99974	.04042	.99918	.05785	.99833	.07527	.99716	41
20	.02327	.99973	.04071	.99917	.05814	.99831	.07556	.99714	40
21	.02356	.99972	.04100	.99916	.05844	.99829	.07585	.99712	39
22	.02385	.99972	.04129	.99915	.05873	.99827	.07614	.99710	38
23	.02414	.99971	.04159	.99913	.05902	.99826	.07643	.99708	37
24	.02443	.99970	.04188	.99912	.05931	.99824	.07672	.99705	36
25	.02472	.99969	.04217	.99911	.05960	.99822	.07701	.99703	35
26	.02501	.99969	.04246	.99910	.05989	.99821	.07730	.99701	34
27	.02530	.99968	.04275	.99909	.06018	.99819	.07759	.99699	33
28	.02560	.99967	.04304	.99907	.06047	.99817	.07788	.99696	32
29	.02589	.99966	.04333	.99906	.06076	.99815	.07817	.99694	31
30	.02618	.99966	.04362	.99905	.06105	.99813	.07846	.99692	30
31	.02647	.99965	.04391	.99904	.06134	.99812	.07875	.99689	29
32	.02676	.99964	.04420	.99902	.06163	.99810	.07904	.99687	28
33	.02705	.99963	.04449	.99901	.06192	.99808	.07933	.99685	27
34	.02734	.99963	.04478	.99900	.06221	.99806	.07962	.99683	26
35	.02763	.99962	.04507	.99898	.06250	.99804	.07991	.99680	25
36	.02792	.99961	.04536	.99897	.06279	.99803	.08020	.99678	24
37	.02821	.99960	.04565	.99896	.06308	.99801	.08049	.99676	23
38	.02850	.99959	.04594	.99894	.06337	.99799	.08078	.99673	22
39	.02879	.99959	.04623	.99893	.06366	.99797	.08107	.99671	21
40	.02908	.99958	.04653	.99892	.06395	.99795	.08136	.99668	20
41	.02938	.99957	.04682	.99890	.06424	.99793	.08165	.99666	19
42	.02967	.99956	.04711	.99889	.06453	.99792	.08194	.99664	18
43	.02996	.99955	.04740	.99888	.06482	.99790	.08223	.99661	17
44	.03025	.99954	.04769	.99886	.06511	.99788	.08252	.99659	16
45	.03054	.99953	.04798	.99885	.06540	.99786	.08281	.99657	15
46	.03083	.99952	.04827	.99883	.06569	.99784	.08310	.99654	14
47	.03112	.99952	.04856	.99882	.06598	.99782	.08339	.99652	13
48	.03141	.99951	.04885	.99881	.06627	.99780	.08368	.99649	12
49	.03170	.99950	.04914	.99879	.06656	.99778	.08397	.99647	11
50	.03199	.99949	.04943	.99878	.06685	.99776	.08426	.99644	10
51	.03228	.99948	.04972	.99876	.06714	.99774	.08455	.99642	9
52	.03257	.99947	.05001	.99875	.06743	.99772	.08484	.99639	8
53	.03286	.99946	.05030	.99873	.06773	.99770	.08513	.99637	7
54	.03316	.99945	.05059	.99872	.06802	.99768	.08542	.99635	6
55	.03345	.99944	.05088	.99870	.06831	.99766	.08571	.99632	5
56	.03374	.99943	.05117	.99869	.06860	.99764	.08600	.99630	4
57	.03403	.99942	.05146	.99867	.06889	.99762	.08629	.99627	3
58	.03432	.99941	.05175	.99866	.06918	.99760	.08658	.99625	2
59	.03461	.99940	.05205	.99864	.06947	.99758	.08687	.99622	1
60	.03490	.99939	.05234	.99863	.06976	.99756	.08716	.99619	0
′	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	′
	88°		87°		86°		85°		

′	5° Sine	5° Cosine	6° Sine	6° Cosine	7° Sine	7° Cosine	8° Sine	8° Cosine	′
0	.08716	.99619	.10453	.99452	.12187	[illegible]	.13917	.99027	60
1	.08745	.99617	.10482	.99449	.12216	.99251	.13946	.99023	59
2	.08774	.99614	.10511	.99446	.12245	.99248	.13975	.99019	58
3	.08803	.99612	.10540	.99443	.12274	.99244	.14004	.99015	57
4	.08831	.99609	.10569	.99440	.12302	.99240	.14033	.99011	56
5	.08860	.99607	.10597	.99437	.12331	.99237	.14061	.99006	55
6	.08889	.99604	.10626	.99434	.12360	.99233	.14090	.99002	54
7	.08918	.99602	.10655	.99431	.12389	.99230	.14119	.98998	53
8	.08947	.99599	.10684	.99428	.12418	.99226	.14148	.98994	52
9	.08976	.99596	.10713	.99424	.12447	.99222	.14177	.98990	51
10	.09005	.99594	.10742	.99421	.12476	.99219	.14205	.98986	50
11	.09034	.99591	.10771	.99418	.12504	.99215	.14234	.98982	49
12	.09063	.99588	.10800	.99415	.12533	.99211	.14263	.98978	48
13	.09092	.99586	.10829	.99412	.12562	.99208	.14292	.98973	47
14	.09121	.99583	.10858	.99409	.12591	[illegible]	.14320	.98969	46
15	.09150	.99580	.10887	.99406	.12620	.99200	.14349	.98965	45
16	.09179	.99578	.10916	.99402	.12649	.99197	.14378	.98961	44
17	.09208	.99575	.10945	.99399	.12678	.99193	.14407	.98957	43
18	.09237	.99572	.10973	.99396	.12706	.99189	.14436	.98953	42
19	.09266	.99570	.11002	.99393	.12735	.99186	.14464	.98948	41
20	.09295	.99567	.11031	.99390	.12764	.99182	.14493	.98944	40
21	.09324	.99564	.11060	.99386	.12793	.99178	.14522	.98940	39
22	.09353	.99562	.11089	.99383	.12822	.99175	.14551	.98936	38
23	.09382	.99559	.11118	.99380	.12851	.99171	.14580	.98931	37
24	.09411	.99556	.11147	.99377	.12880	.99167	.14608	.98927	36
25	.09440	.99553	.11176	.99374	.12908	.99163	.14637	.98923	35
26	.09469	.99551	.11205	.99370	.12937	.99160	.14666	.98919	34
27	.09498	.99548	.11234	.99367	.12966	.99156	.14695	.98914	33
28	.09527	.99545	.11263	.99364	.12995	.99152	.14723	.98910	32
29	.09556	.99542	.11291	.99360	.13024	.99148	.14752	.98906	31
30	.09585	.99540	.11320	.99357	.13053	.99144	.14781	.98902	30
31	.09614	.99537	.11349	.99354	.13081	.99141	.14810	.98897	29
32	.09642	.99534	.11378	.99351	.13110	.99137	.14838	.98893	28
33	.09671	.99531	.11407	.99347	.13139	[illegible]	.14867	.98889	27
34	.09700	.99528	.11436	.99344	.13168	.99129	.14896	.98884	26
35	.09729	.99526	.11465	.99341	.13197	.99125	.14925	.98880	25
36	.09758	.99523	.11494	.99337	.13226	.99122	.14954	.98876	24
37	.09787	.99520	.11523	.99334	.13254	.99118	.14982	.98871	23
38	.09816	.99517	.11552	.99331	.13283	.99114	.15011	.98867	22
39	.09845	.99514	.11580	.99327	.13312	.99110	.15040	.98863	21
40	.09874	.99511	.11609	.99324	.13341	.99106	.15069	.98858	20
41	.09903	.99508	.11638	.99320	.13370	.99102	.15097	.98854	19
42	.09932	.99506	.11667	.99317	.13399	.99098	.15126	.98849	18
43	.09961	.99503	.11696	.99314	.13427	.99094	.15155	.98845	17
44	.09990	.99500	.11725	.99310	.13456	.99091	.15184	.98841	16
45	.10019	.99497	.11754	.99307	.13485	.99087	.15212	.98836	15
46	.10048	.99494	.11783	.99303	.13514	.99083	.15241	.98832	14
47	.10077	.99491	.11812	.99300	.13543	.99079	.15270	.98827	13
48	.10106	.99488	.11840	.99297	.13572	.99075	.15299	.98823	12
49	.10135	.99485	.11869	.99293	.13600	.99071	.15327	.98818	11
50	.10164	.99482	.11898	.99290	.13629	.99067	.15356	.98814	10
51	.10192	.99479	.11927	.99286	.13658	.99063	.15385	.98809	9
52	.10221	.99476	.11956	.99283	.13687	.99059	.15414	.98805	8
53	.10250	.99473	.11985	.99279	.13716	.99055	.15442	.98800	7
54	.10279	.99470	.12014	.99276	.13744	.99051	.15471	.98796	6
55	.10308	.99467	.12043	.99272	.13773	.99047	.15500	.98791	5
56	.10337	.99464	.12071	.99269	.13802	[illegible]	.15529	.98787	4
57	.10366	.99461	.12100	.99265	.13831	.99039	.15557	.98782	3
58	.10395	.99458	.12129	.99262	.13860	.99035	.15586	.98778	2
59	.10424	.99455	.12158	.99258	.13889	.99031	.15615	.98773	1
60	.10453	.99452	.12187	.99255	.13917	.99027	.15643	.98769	0
′	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	′
	84°		83°		82°		81°		

9° Sine	9° Cosine	10° Sine	10° Cosine	11° Sine	11° Cosine	12° Sine	12° Cosine	′
.15643	.98769	.17365	.98481	.19081	.98163	.20791	.97815	60
.15672	.98764	.17393	.98476	.19109	.98157	.20820	.97809	59
.15701	.98760	.17422	.98471	.19138	.98152	.20848	.97803	58
.15730	.98755	.17451	.98466	.19167	.98146	.20877	.97797	57
.15758	.98751	.17479	.98461	.19195	.98140	.20905	.97791	56
.15787	.98746	.17508	.98455	.19224	.98135	.20933	.97784	55
.15816	.98741	.17537	.98450	.19252	.98129	.20962	.97778	54
.15845	.98737	.17565	.98445	.19281	.98124	.20990	.97772	53
.15873	.98732	.17594	.98440	.19309	.98118	.21019	.97766	52
.15902	.98728	.17623	.98435	.19338	.98112	.21047	.97760	51
.15931	.98723	.17651	.98430	.19366	.98107	.21076	.97754	50
.15959	.98718	.17680	.98425	.19395	.98101	.21104	.97748	49
.15988	.98714	.17708	.98420	.19423	.98096	.21132	.97742	48
.16017	.98709	.17737	.98414	.19452	.98090	.21161	.97735	47
.16046	.98704	.17766	.98409	.19481	.98084	.21189	.97729	46
.16074	.98700	.17794	.98404	.19509	.98079	.21218	.97723	45
.16103	.98695	.17823	.98399	.19538	.98073	.21246	.97717	44
.16132	.98690	.17852	.98394	.19566	.98067	.21275	.97711	43
.16160	.98689	.17880	.98389	.19595	.98061	.21303	.97705	42
.16189	.98681	.17909	.98383	.19623	.98056	.21331	.97698	41
.16218	.98676	.17937	.98378	.19652	.98050	.21360	.97692	40
.16246	.98671	.17966	.98373	.19680	.98044	.21388	.97686	39
.16275	.98667	.17995	.98368	.19709	.98039	.21417	.97680	38
.16304	.98662	.18023	.98362	.19737	.98033	.21445	.97673	37
.16333	.98657	.18052	.98357	.19766	.98027	.21474	.97667	36
.16361	.98652	.18081	.98352	.19794	.98021	.21502	.97661	35
.16390	.98648	.18109	.98347	.19823	.98016	.21530	.97655	34
.16419	.98643	.18138	.98341	.19851	.98010	.21559	.97648	33
.16447	.98638	.18166	.98336	.19880	.98004	.21587	.97642	32
.16476	.98633	.18195	.98331	.19908	.97987	.21616	.97636	31
.16505	.98629	.18224	.98325	.19937	.97992	.21644	.97630	30
.16533	.98624	.18252	.98320	.19965	.97987	.21672	.97623	29
.16562	.98619	.18281	.98315	.19994	.97981	.21701	.97617	28
.16591	.98614	.18309	.98310	.20022	.97975	.21729	.97611	27
.16620	.98609	.18338	.98304	.20031	.97969	.21758	.97604	26
.16648	.98604	.18367	.98299	.20079	.97963	.21786	.97598	25
.16677	.98600	.18395	.98294	.20108	.97958	.21814	.97592	24
.16706	.98595	.18424	.98288	.20136	.97952	.21843	.97585	23
.16734	.98590	.18452	.98283	.20165	.97946	.21871	.97579	22
.16763	.98585	.18481	.98277	.20193	.97940	.21899	.97573	21
.16792	.98580	.18509	.98272	.20222	.97934	.21928	.97566	20
.16820	.98575	.18538	.98267	.20250	.97928	.21956	.97560	19
.16849	.98570	.18567	.98261	.20279	.97922	.21985	.97553	18
.16878	.98565	.18595	.98256	.20307	.97916	.22013	.97547	17
.16906	.98561	.18624	.98250	.20336	.97910	.22041	.97541	16
.16935	.98556	.18652	.98245	.20364	.97905	.22070	.97534	15
.16964	.98551	.18681	.98240	.20393	.97899	.22098	.97528	14
.16992	.98546	.18710	.98234	.20421	.97893	.22126	.97521	13
.17021	.98541	.18738	.98229	.20450	.97887	.22155	.97515	12
.17050	.98536	.18767	.98223	.20478	.97881	.22183	.97508	11
.17078	.98531	.18795	.98218	.20507	.97875	.22212	.97502	10
.17107	.98526	.18824	.98212	.20535	.97869	.22240	.97496	9
.17136	.98521	.18852	.98207	.20563	.97863	.22268	.97489	8
.17164	.98516	.18881	.98201	.20592	.97857	.22297	.97483	7
.17193	.98511	.18910	.98196	.20620	.97851	.22325	.97476	6
.17222	.98506	.18938	.98190	.20649	.97845	.22353	.97470	5
.17250	.98501	.18967	.98185	.20677	.97839	.22382	.97463	4
.17279	.98496	.18995	.98179	.20706	.97833	.22410	.97457	3
.17308	.98491	.19024	.98174	.20734	.97827	.22438	.97450	2
.17336	.98486	.19052	.98168	.20763	.97821	.22467	.97444	1
.17365	.98481	.19081	.98163	.20791	.97815	.22495	.97437	0
80° Cosine	80° Sine	79° Cosine	79° Sine	78° Cosine	78° Sine	77° Cosine	77° Sine	′

	13°		14°		15°		16°		
′	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	′
0	.22495	.97437	.24192	.97030	.25882	.96593	.27564	.96126	60
1	.22523	.97430	.24220	.97023	.25910	.96585	.27592	.96118	59
2	.22552	.97424	.24249	.97015	.25938	.96578	.27620	.96110	58
3	.22580	.97417	.24277	.97008	.25966	.96570	.27648	.96102	57
4	.22608	.97411	.24305	.97001	.25994	.96562	.27676	.96094	56
5	.22637	.97404	.24333	.96994	.26022	.96555	.27704	.96086	55
6	.22665	.97398	.24362	.96987	.26050	.96547	.27731	.96078	54
7	.22693	.97391	.24390	.96980	.26079	.96540	.27759	.96070	53
8	.22722	.97384	.24418	.96973	.26107	.96532	.27787	.96062	52
9	.22750	.97378	.24446	.96966	.26135	.96524	.27815	.96054	51
10	.22778	.97371	.24474	.96959	.26163	.96517	.27843	.96046	50
11	.22807	.97365	.24503	.96952	.26191	.96509	.27871	.96037	49
12	.22835	.97358	.24531	.96945	.26219	.96502	.27899	.96029	48
13	.22863	.97351	.24559	.96937	.26247	.96494	.27927	.96021	47
14	.22892	.97345	.24587	.96930	.26275	.96486	.27955	.96013	46
15	.22920	.97338	.24615	.96923	.26303	.96479	.27983	.96005	45
16	.22948	.97331	.24644	.96916	.26331	.96471	.28011	.95997	44
17	.22977	.97325	.24672	.96909	.26359	.96463	.28039	.95989	43
18	.23005	.97318	.24700	.96902	.26387	.96456	.28067	.95981	42
19	.23033	.97311	.24728	.96894	.26415	.96448	.28095	.95972	41
20	.23062	.97304	.24756	.96887	.26443	.96440	.28123	.95964	40
21	.23090	.97298	.24784	.96880	.26471	.96433	.28150	.95956	39
22	.23118	.97291	.24813	.96873	.26500	.96425	.28178	.95948	38
23	.23146	.97284	.24841	.96866	.26528	.96417	.28206	.95940	37
24	.23175	.97278	.24869	.96858	.26556	.96410	.28234	.95931	36
25	.23203	.97271	.24897	.96851	.26584	.96402	.28262	.95923	35
26	.23231	.97264	.24925	.96844	.26612	.96394	.28290	.95915	34
27	.23260	.97257	.24954	.96837	.26640	.96386	.28318	.95907	33
28	.23288	.97251	.24982	.96829	.26668	.96379	.28346	.95898	32
29	.23316	.97244	.25010	.96822	.26696	.96371	.28374	.95890	31
30	.23345	.97237	.25038	.96815	.26724	.96363	.28402	.95882	30
31	.23373	.97230	.25066	.96807	.26752	.96355	.28429	.95874	29
32	.23401	.97223	.25094	.96800	.26780	.96347	.28457	.95865	28
33	.23429	.97217	.25122	.96793	.26808	.96340	.28485	.95857	27
34	.23458	.97210	.25151	.96786	.26836	.96332	.28513	.95849	26
35	.23486	.97203	.25179	.96778	.26864	.96324	.28541	.95841	25
36	.23514	.97196	.25207	.96771	.26892	.96316	.28569	.95832	24
37	.23542	.97189	.25235	.96764	.26920	.96308	.28597	.95824	23
38	.23571	.97182	.25263	.96756	.26948	.96301	.28625	.95816	22
39	.23599	.97176	.25291	.96749	.26976	.96293	.28652	.95807	21
40	.23627	.97169	.25320	.96742	.27004	.96285	.28680	.95799	20
41	.23656	.97162	.25348	.96734	.27032	.96277	.28708	.95791	19
42	.23684	.97155	.25376	.96727	.27060	.96269	.28736	.95782	18
43	.23712	.97148	.25404	.96719	.27088	.96261	.28764	.95774	17
44	.23740	.97141	.25432	.96712	.27116	.96253	.28792	.95766	16
45	.23769	.97134	.25460	.96705	.27144	.96246	.28820	.95757	15
46	.23797	.97127	.25488	.96697	.27172	.96238	.28847	.95749	14
47	.23825	.97120	.25516	.96690	.27200	.96230	.28875	.95740	13
48	.23853	.97113	.25545	.96682	.27228	.96222	.28903	.95732	12
49	.23882	.97106	.25573	.96675	.27256	.96214	.28931	.95724	11
50	.23910	.97100	.25601	.96667	.27284	.96206	.28959	.95715	10
51	.23938	.97093	.25629	.96660	.27312	.96198	.28987	.95707	9
52	.23966	.97086	.25657	.96653	.27340	.96190	.29015	.95698	8
53	.23995	.97079	.25685	.96645	.27368	.96182	.29042	.95690	7
54	.24023	.97072	.25713	.96638	.27396	.96174	.29070	.95681	6
55	.24051	.97065	.25741	.96630	.27424	.96166	.29098	.95673	5
56	.24079	.97058	.25769	.96623	.27452	.96158	.29126	.95664	4
57	.24107	.97051	.25798	.96615	.27480	.96150	.29154	.95656	3
58	.24136	.97044	.25826	.96608	.27508	.96142	.29182	.95647	2
59	.24164	.97037	.25854	.96600	.27536	.96134	.29209	.95639	1
60	.24192	.97030	.25882	.96593	.27564	.96126	.29237	.95630	0
′	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	′
	76°		75°		74°		73°		

17°		18°		19°		20°		
Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	′
.29237	.95630	.30902	.95106	.32557	.94552	.34202	.93969	60
.29265	.95622	.30929	.95097	.32584	.94542	.34229	.93959	59
.29293	.95613	.30957	.95088	.32612	.94533	.34257	.93949	58
.29321	.95605	.30985	.95079	.32639	.94523	.34284	.93939	57
.29348	.95596	.31012	.95070	.32667	.94514	.34311	.93929	56
.29376	.95588	.31040	.95061	.32694	.94504	.34339	.93919	55
.29404	.95579	.31068	.95052	.32722	.94495	.34366	.93909	54
.29432	.95571	.31095	.95043	.32749	.94485	.34393	.93899	53
.29460	.95562	.31123	.95033	.32777	.94476	.34421	.93889	52
.29487	.95554	.31151	.95024	.32804	.94466	.34448	.93879	51
.29515	.95545	.31178	.95015	.32832	.94457	.34475	.93869	50
.29543	.95536	.31206	.95006	.32859	.94447	.34503	.93859	49
.29571	.95528	.31233	.94997	.32887	.94438	.34530	.93849	48
.29599	.95519	.31261	.94988	.32914	.94428	.34557	.93839	47
.29626	.95511	.31289	.94979	.32942	.94418	.34584	.93829	46
.29654	.95502	.31316	.94970	.32969	.94409	.34612	.93819	45
.29682	.95493	.31344	.94961	.32997	.94399	.34639	.93809	44
.29710	.95485	.31372	.94952	.33024	.94390	.34666	.93799	43
.29737	.95476	.31399	.94943	.33051	.94380	.34694	.93789	42
.29765	.95467	.31427	.94933	.33079	.94370	.34721	.93779	41
.29793	.95459	.31454	.94924	.33106	.94361	.34748	.93769	40
.29821	.95450	.31482	.94915	.33134	.94351	.34775	.93759	39
.29849	.95441	.31510	.94906	.33161	.94342	.34803	.93748	38
.29876	.95433	.31537	.94897	.33189	.94332	.34830	.93738	37
.29904	.95424	.31565	.94888	.33216	.94322	.34857	.93728	36
.29932	.95415	.31593	.94878	.33244	.94313	.34884	.93718	35
.29960	.95407	.31620	.94869	.33271	.94303	.34912	.93708	34
.29987	.95398	.31648	.94860	.33298	.94293	.34939	.93698	33
.30015	.95389	.31675	.94851	.33326	.94284	.34966	.93688	32
.30043	.95380	.31703	.94842	.33353	.94274	.34993	.93677	31
.30071	.95372	.31730	.94832	.33381	.94264	.35021	.93667	30
.30098	.95363	.31758	.94823	.33408	.94254	.35048	.93657	29
.30126	.95354	.31786	.94814	.33436	.94245	.35075	.93647	28
.30154	.95345	.31813	.94805	.33463	.94235	.35102	.93637	27
.30182	.95337	.31841	.94795	.33490	.94225	.35130	.93626	26
.30209	.95328	.31868	.94786	.33518	.94215	.35157	.93616	25
.30237	.95319	.31896	.94777	.33545	.94206	.35184	.93606	24
.30265	.95310	.31923	.94768	.33573	.94196	.35211	.93596	23
.30292	.95301	.31951	.94758	.33600	.94186	.35239	.93585	22
.30320	.95293	.31979	.94749	.33627	.94176	.35266	.93575	21
.30348	.95284	.32006	.94740	.33655	.94167	.35293	.93565	20
.30376	.95275	.32034	.94730	.33682	.94157	.35320	.93555	19
.30403	.95266	.32061	.94721	.33710	.94147	.35347	.93544	18
.30431	.95257	.32089	.94712	.33737	.94137	.35375	.93534	17
.30459	.95248	.32116	.94702	.33764	.94127	.35402	.93524	16
.30486	.95240	.32144	.94693	.33792	.94118	.35429	.93514	15
.30514	.95231	.32171	.94684	.33819	.94108	.35456	.93503	14
.30542	.95222	.32199	.94674	.33846	.94098	.35484	.93493	13
.30570	.95213	.32227	.94665	.33874	.94088	.35511	.93483	12
.30597	.95204	.32254	.94656	.33901	.94078	.35538	.93472	11
.30625	.95195	.32282	.94646	.33929	.94068	.35565	.93462	10
.30653	.95186	.32309	.94637	.33956	.94058	.35592	.93452	9
.30680	.95177	.32337	.94627	.33983	.94049	.35619	.93441	8
.30708	.95168	.32364	.94618	.34011	.94039	.35647	.93431	7
.30736	.95159	.32392	.94609	.34038	.94029	.35674	.93420	6
.30763	.95150	.32419	.94599	.34065	.94019	.35701	.93410	5
.30791	.95142	.32447	.94590	.34093	.94009	.35728	.93400	4
.30819	.95133	.32474	.94580	.34120	.93999	.35755	.93389	3
.30846	.95124	.32502	.94571	.34147	.93989	.35782	.93379	2
.30874	.95115	.32529	.94561	.34175	.93979	.35810	.93368	1
.30902	.95106	.32557	.94552	.34202	.93969	.35837	.93358	0
Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	′
72°		71°		70°		69°		

′	21° Sine	21° Cosine	22° Sine	22° Cosine	23° Sine	23° Cosine	24° Sine	24° Cosine	′
0	.35837	.93358	.37461	.92718	.39073	.92050	.40674	.91355	60
1	.35864	.93348	.37488	.92707	.39100	.92039	.40700	.91343	59
2	.35891	.93337	.37515	.92697	.39127	.92028	.40727	.91331	58
3	.35918	.93327	.37542	.92686	.39153	.92016	.40753	.91319	57
4	.35945	.93316	.37569	.92675	.39180	.92005	.40780	.91307	56
5	.35973	.93306	.37595	.92664	.39207	.91994	.40806	.91295	55
6	.36000	.93295	.37622	.92653	.39234	.91982	.40833	.91283	54
7	.36027	.93285	.37649	.92642	.39260	.91971	.40860	.91272	53
8	.36054	.93274	.37676	.92631	.39287	.91959	.40886	.91260	52
9	.36081	.93264	.37703	.92620	.39314	.91948	.40913	.91248	51
10	.36108	.93253	.37730	.92609	.39341	.91936	.40939	.91236	50
11	.36135	.93243	.37757	.92598	.39367	.91925	.40966	.91224	49
12	.36162	.93232	.37784	.92587	.39394	.91914	.40992	.91212	48
13	.36190	.93222	.37811	.92576	.39421	.91902	.41019	.91200	47
14	.36217	.93211	.37838	.92565	.39448	.91891	.41045	.91188	46
15	.36244	.93201	.37865	.92554	.39474	.91879	.41072	.91176	45
16	.36271	.93190	.37892	.92543	.39501	.91868	.41098	.91164	44
17	.36298	.93180	.37919	.92532	.39528	.91856	.41125	.91152	43
18	.36325	.93169	.37946	.92521	.39555	.91845	.41151	.91140	42
19	.36352	.93159	.37973	.92510	.39581	.91833	.41178	.91128	41
20	.36379	.93148	.37999	.92499	.39608	.91822	.41204	.91116	40
21	.36406	.93137	.38026	.92488	.39635	.91810	.41231	.91104	39
22	.36434	.93127	.38053	.92477	.39661	.91799	.41257	.91092	38
23	.36461	.93116	.38080	.92466	.39688	.91787	.41284	.91080	37
24	.36488	.93106	.38107	.92455	.39715	.91775	.41310	.91068	36
25	.36515	.93095	.38134	.92444	.39741	.91764	.41337	.91056	35
26	.36542	.93084	.38161	.92432	.39768	.91752	.41363	.91044	34
27	.36569	.93074	.38188	.92421	.39795	.91741	.41390	.91032	33
28	.36596	.93063	.38215	.92410	.39822	.91729	.41416	.91020	32
29	.36623	.93052	.38241	.92399	.39848	.91718	.41443	.91008	31
30	.36650	.93042	.38268	.92388	.39875	.91706	.41469	.90996	30
31	.36677	.93031	.38295	.92377	.39902	.91694	.41496	.90984	29
32	.36704	.93020	.38322	.92366	.39928	.91683	.41522	.90972	28
33	.36731	.93010	.38349	.92355	.39955	.91671	.41549	.90960	27
34	.36758	.92999	.38376	.92343	.39982	.91660	.41575	.90948	26
35	.36785	.92988	.38403	.92332	.40008	.91648	.41602	.90936	25
36	.36812	.92978	.38430	.92321	.40035	.91636	.41628	.90924	24
37	.36839	.92967	.38456	.92310	.40062	.91625	.41655	.90911	23
38	.36867	.92956	.38483	.92299	.40088	.91613	.41681	.90899	22
39	.36894	.92945	.38510	.92287	.40115	.91601	.41707	.90887	21
40	.36921	.92935	.38537	.92276	.40141	.91590	.41734	.90875	20
41	.36948	.92924	.38564	.92265	.40168	.91578	.41760	.90863	19
42	.36975	.92913	.38591	.92254	.40195	.91566	.41787	.90851	18
43	.37002	.92902	.38617	.92243	.40221	.91555	.41813	.90839	17
44	.37029	.92892	.38644	.92231	.40248	.91543	.41840	.90826	16
45	.37056	.92881	.38671	.92220	.40275	.91531	.41866	.90814	15
46	.37083	.92870	.38698	.92209	.40301	.91519	.41892	.90802	14
47	.37110	.92859	.38725	.92198	.40328	.91508	.41919	.90790	13
48	.37137	.92849	.38752	.92186	.40355	.91496	.41945	.90778	12
49	.37164	.92838	.38778	.92175	.40381	.91484	.41972	.90766	11
50	.37191	.92827	.38805	.92164	.40408	.91472	.41998	.90753	10
51	.37218	.92816	.38832	.92152	.40434	.91461	.42024	.90741	
52	.37245	.92805	.38859	.92141	.40461	.91449	.42051	.90729	
53	.37272	.92794	.38886	.92130	.40488	.91437	.42077	.90717	
54	.37299	.92784	.38912	.92119	.40514	.91425	.42104	.90704	
55	.37326	.92773	.38939	.92107	.40541	.91414	.42130	.90692	
56	.37353	.92762	.38966	.92096	.40567	.91402	.42156	.90680	
57	.37380	.92751	.38993	.92085	.40594	.91390	.42183	.90668	
58	.37407	.92740	.39020	.92073	.40621	.91378	.42209	.90655	
59	.37434	.92729	.39046	.92062	.40647	.91366	.42235	.90643	
60	.37461	.92718	.39073	.92050	.40674	.91355	.42262	.90631	
′	Cosine 68°	Sine 68°	Cosine 67°	Sine 67°	Cosine 66°	Sine 66°	Cosine 65°	Sine 65°	′

25°		26°		27°		28°		
Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	′
.42262	.90631	.43837	.89879	.45399	.89101	.46947	.88295	60
.42288	.90618	.43863	.89867	.45425	.89087	.46973	.88281	59
.42315	.90606	.43889	.89854	.45451	.89074	.46999	.88267	58
.42341	.90594	.43916	.89841	.45477	.89061	.47024	.88254	57
.42367	.90582	.43942	.89828	.45503	.89048	.47050	.88240	56
.42394	.90569	.43968	.89816	.45529	.89035	.47076	.88226	55
.42420	.90557	.43994	.89803	.45554	.89021	.47101	.88213	54
.42446	.90545	.44020	.89790	.45580	.89008	.47127	.88199	53
.42473	.90532	.44046	.89777	.45606	.88995	.47153	.88185	52
.42499	.90520	.44072	.89764	.45632	.88981	.47178	.88172	51
.42525	.90507	.44098	.89752	.45658	.88968	.47204	.88158	50
.42552	.90495	.44124	.89739	.45684	.88955	.47229	.88144	49
.42578	.90483	.44151	.89726	.45710	.88942	.47255	.88130	48
.42604	.90470	.44177	.89713	.45736	.88928	.47281	.88117	47
.42631	.90458	.44203	.89700	.45762	.88915	.47306	.88103	46
.42657	.90446	.44229	.89687	.45787	.88902	.47332	.88089	45
.42683	.90433	.44255	.89674	.45813	.88888	.47358	.88075	44
.42709	.90421	.44281	.89662	.45839	.88875	.47383	.88062	43
.42736	.90408	.44307	.89649	.45865	.88862	.47409	.88048	42
.42762	.90396	.44333	.89636	.45891	.88848	.47434	.88034	41
.42788	.90383	.44359	.89623	.45917	.88835	.47460	.88020	40
.42815	.90371	.44385	.89610	.45942	.88822	.47486	.88006	39
.42841	.90358	.44411	.89597	.45968	.88808	.47511	.87993	38
.42867	.90346	.44437	.89584	.45994	.88795	.47537	.87979	37
.42894	.90334	.44464	.89571	.46020	.88782	.47562	.87965	36
.42920	.90321	.44490	.89558	.46046	.88768	.47588	.87951	35
.42946	.90309	.44516	.89545	.46072	.88755	.47614	.87937	34
.42972	.90296	.44542	.89532	.46097	.88741	.47639	.87923	33
.42999	.90284	.44568	.89519	.46123	.88728	.47665	.87909	32
.43025	.90271	.44594	.89506	.46149	.88715	.47690	.87896	31
.43051	.90259	.44620	89493	.46175	.88701	.47716	.87882	30
.43077	.90246	.44646	.89480	.46201	.88688	.47741	.87868	29
.43104	.90233	.44672	.89467	.46226	.88674	.47767	.87854	28
.43130	.90221	.44698	.89454	.46252	.88661	.47793	.87840	27
.43156	.90208	.44724	.89441	.46278	.88647	.47818	.87826	26
.43182	.90196	.44750	.89428	.46304	.88634	.47844	.87812	25
.43209	.90183	.44776	.89415	.46330	.88620	.47869	.87798	24
.43235	.90171	.44802	.89402	.46355	.88607	.47895	.87784	23
.43261	.90158	.44828	.89389	.46381	.88593	.47920	.87770	22
.43287	.90146	.44854	.89376	.46407	.88580	.47946	.87756	21
.43313	.90133	.44880	.89363	.46433	.88566	.47971	.87743	20
.43340	.90120	.44906	.89350	.46458	.88553	.47997	.87729	19
.43366	.90108	.44932	.89337	.46484	.88539	.48022	.87715	18
.43392	.90095	.44958	.89324	.46510	.88526	.48048	.87701	17
.43418	.90082	.44984	.89311	.46536	.88512	.48073	.87687	16
.43445	.90070	.45010	.89298	.46561	.88499	.48099	.87673	15
.43471	.90057	.45036	.89285	.46587	.88485	.48124	.87659	14
.43497	.90045	.45062	.89272	.46613	.88472	.48150	.87645	13
.43523	.90032	.45088	.89259	.46639	.88458	.48175	.87631	12
.43549	.90019	.45114	.89245	.46664	.88445	.48201	.87617	11
.43575	.90007	.45140	.89232	.46690	.88431	.48226	.87603	10
.43602	.89994	.45166	.89219	.46716	.88417	.48252	.87589	9
.43628	.89981	45192	.89206	.46742	.88404	.48277	.87575	8
.43654	.89968	.45218	.89193	.46767	.88390	.48303	.87561	7
.43680	.89956	.45243	.89180	.46793	.88377	.48328	.87546	6
.43706	.89943	.45269	.89167	.46819	.88363	.48354	.87532	5
.43733	.89930	.45295	.89153	.46844	.88349	.48379	.87518	4
.43759	.89918	.45321	.89140	.46870	.88336	.48405	.87504	3
.43785	.89905	.45347	.89127	.46896	.88322	.48430	.87490	2
.43811	.89892	.45373	.89114	.46921	.88308	.48456	.87476	1
.43837	.89879	.45399	.89101	.46947	.88295	.48481	.87462	0
Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	′
64°		63°		62°		61°		

′	29° Sine	29° Cosine	30° Sine	30° Cosine	31° Sine	31° Cosine	32° Sine	32° Cosine	′
0	.48481	.87462	.50000	.86603	.51504	.85717	.52992	.84805	60
1	.48506	.87448	.50025	.86588	.51529	.85702	.53017	.84789	59
2	.48532	.87434	.50050	.86573	.51554	.85687	.53041	.84774	58
3	.48557	.87420	.50076	.86559	.51579	.85672	.53066	.84759	57
4	.48583	.87406	.50101	.86544	.51604	.85657	.53091	.84743	56
5	.48608	.87391	.50126	.86530	.51628	.85642	.53115	.84728	55
6	.48634	.87377	.50151	.86515	.51653	.85627	.53140	.84712	54
7	.48659	.87363	.50176	.86501	.51678	.85612	.53164	.84697	53
8	.48684	.87349	.50201	.86486	.51703	.85597	.53189	.84681	52
9	.48710	.87335	.50227	.86471	.51728	.85582	.53214	.84666	51
10	.48735	.87321	.50252	.86457	.51753	.85567	.53238	.84650	50
11	.48761	.87306	.50277	.86442	.51778	.85551	.53263	.84635	49
12	.48786	.87292	.50302	.86427	.51803	.85536	.53288	.84619	48
13	.48811	.87278	.50327	.86413	.51828	.85521	.53312	.84604	47
14	.48837	.87264	.50352	.86398	.51852	.85506	.53337	.84588	46
15	.48862	.87250	.50377	.86384	.51877	.85491	.53361	.84573	45
16	.48888	.87235	.50403	.86369	.51902	.85476	.53386	.84557	44
17	.48913	.87221	.50428	.86354	.51927	.85461	.53411	.84542	43
18	.48938	.87207	.50453	.86340	.51952	.85446	.53435	.84526	42
19	.48964	.87193	.50478	.86325	.51977	.85431	.53460	.84511	41
20	.48989	.87178	.50503	.86310	.52002	.85416	.53484	.84495	40
21	.49014	.87164	.50528	.86295	.52026	.85401	.53509	.84480	39
22	.49040	.87150	.50553	.86281	.52051	.85385	.53534	.84464	38
23	.49065	.87136	.50578	.86266	.52076	.85370	.53558	.84448	37
24	.49090	.87121	.50603	.86251	.52101	.85355	.53583	.84433	36
25	.49116	.87107	.50628	.86237	.52126	.85340	.53607	.84417	35
26	.49141	.87093	.50654	.86222	.52151	.85325	.53632	.84402	34
27	49166	.87079	.50679	.86207	.52175	.85310	.53656	.84386	33
28	.49192	.87064	.50704	.86192	.52200	.85294	.53681	.84370	32
29	.49217	.87050	.50729	.86178	.52225	.85279	.53705	.84355	31
30	.49242	.87036	.50754	.86163	.52250	.85264	.53730	.84339	30
31	.49268	.87021	.50779	.86148	.52275	.85249	.53754	.84324	29
32	.49293	.87007	.50804	.86133	.52299	.85234	.53779	.84308	28
33	.49318	.86993	.50829	.86119	.52324	.85218	.53804	.84292	27
34	.49344	.86978	.50854	.86104	.52349	.85203	.53828	.84277	26
35	.49369	.86964	.50879	.86089	.52374	.85188	.53853	.84261	25
36	.49394	.86949	.50904	.86074	.52399	.85173	.53877	.84245	24
37	.49419	.86935	.50929	.86059	.52423	.85157	.53902	.84230	23
38	.49445	.86921	.50954	.86045	.52448	.85142	.53926	.84214	22
39	.49470	.86906	.50979	.86030	.52473	.85127	.53951	.84198	21
40	.49495	.86892	.51004	.86015	.52498	.85112	.53975	.84182	20
41	.49521	.86878	.51029	.86000	.52522	.85096	.54000	.84167	19
42	.49546	.86863	.51054	.85985	.52547	.85081	.54024	.84151	18
43	.49571	.86849	.51079	.85970	.52572	.85066	.54049	.84135	17
44	.49596	.86834	.51104	.85956	.52597	.85051	.54073	.84120	16
45	.49622	.86820	.51129	.85941	.52621	.85035	.54097	.84104	15
46	.49647	.86805	.51154	.85926	.52646	.85020	.54122	.84088	14
47	.49672	.86791	.51179	.85911	.52671	.85005	.54146	.84072	13
48	.49697	.86777	.51204	.85896	.52696	.84989	.54171	.84057	12
49	.49723	.86762	.51229	.85881	.52720	.84974	.54195	.84041	11
50	.49748	.86748	.51254	.85866	.52745	.84959	.54220	.84025	10
51	.49773	.86733	.51279	.85851	.52770	.84943	.54244	.84009	9
52	.49798	.86719	.51304	.85836	.52794	.84928	.54269	.83994	8
53	.49824	.86704	.51329	.85821	.52819	.84913	.54293	.83978	7
54	.49849	.86690	.51354	.85806	.52844	.84897	.54317	.83962	6
55	.49874	.86675	.51379	.85792	.52869	.84882	.54342	.83946	5
56	.49899	.86661	.51404	.85777	.52893	.84866	.54366	.83930	4
57	.49924	.86646	.51429	.85762	.52918	.84851	.54391	.83915	3
58	.49950	.86632	.51454	.85747	.52943	.84836	.54415	.83899	2
59	.49975	.86617	.51479	.85732	.52967	.84820	.54440	.83883	1
60	.50000	.86603	.51504	.85717	.52992	.84805	.54464	.83867	0
′	Cosine 60°	Sine 60°	Cosine 59°	Sine 59°	Cosine 58°	Sine 58°	Cosine 57°	Sine 57°	′

33°		34°		35°		36°		
Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	′
.54464	.83867	.55919	.82904	.57358	.81915	.58779	.80902	60
.54488	.83851	.55943	.82887	.57381	.81899	.58802	.80885	59
.54513	.83835	.55968	.82871	.57405	.81882	.58826	.80867	58
.54537	.83819	.55992	.82855	.57429	.81865	.58849	.80850	57
.54561	.83804	.56016	.82839	.57453	.81848	.58873	.80833	56
.54586	.83788	.56040	.82822	.57477	.81832	.58896	.80816	55
.54610	.83772	.56064	.82806	.57501	.81815	.58920	.80799	54
.54635	.83756	.56088	.82790	.57524	.81798	.58943	.80782	53
.54659	.83740	.56112	.82773	.57548	.81782	.58967	.80765	52
.54683	.83724	.56136	.82757	.57572	.81765	.58990	.80748	51
.54708	.83708	.56160	.82741	.57596	.81748	.59014	.80730	50
.54732	.83692	.56184	.82724	.57619	.81731	.59037	.80713	49
.54756	.83676	.56208	.82708	.57643	.81714	.59061	.80696	48
.54781	.83660	.56232	.82692	.57667	.81698	.59084	.80679	47
.54805	.83645	.56256	.82675	.57691	.81681	.59108	.80662	46
.54829	.83629	.56280	.82659	.57715	.81664	.59131	.80644	45
.54854	.83613	.56305	.82643	.57738	.81647	.59154	.80627	44
.54878	.83597	.56329	.82626	.57762	.81631	.59178	.80610	43
.54902	.83581	.56353	.82610	.57786	.81614	.59201	.80593	42
.54927	.83565	.56377	.82593	.57810	.81597	.59225	.80576	41
.54951	.83549	.56401	.82577	.57833	.81580	.59248	.80558	40
.54975	.83533	.56425	.82561	.57857	.81563	.59272	.80541	39
.55000	.83517	.56449	.82544	.57881	.81546	.59295	.80524	38
.55024	.83501	.56473	.82528	.57904	.81530	.59318	.80507	37
.55048	.83485	.56497	.82511	.57928	.81513	.59342	.80489	36
.55072	.83469	.56521	.82495	.57952	.81496	.59365	.80472	35
.55097	.83453	.56545	.82478	.57976	.81479	.59389	.80455	34
.55121	.83437	.56569	.82462	.57999	.81462	.59412	.80438	33
.55145	.83421	.56593	.82446	.58023	.81445	.59436	.80420	32
.55169	.83405	.56617	.82429	.58047	.81428	.59459	.80403	31
.55194	.83389	.56641	.82413	.58070	.81412	.59482	.80386	30
.55218	.83373	.56665	.82396	.58094	.81395	.59506	.80368	29
.55242	.83356	.56689	.82380	.58118	.81378	.59529	.80351	28
.55266	.83340	.56713	.82363	.58141	.81361	.59552	.80334	27
.55291	.83324	.56736	.82347	.58165	.81344	.59576	.80316	26
.55315	.83308	.56760	.82330	.58189	.81327	.59599	.80299	25
.55339	.83292	.56784	.82314	.58212	.81310	.59622	.80282	24
.55363	.83276	.56808	.82297	.58236	.81293	.59646	.80264	23
.55388	.83260	.56832	.82281	.58260	.81276	.59669	.80247	22
.55412	.83244	.56856	.82264	.58283	.81259	.59693	.80230	21
.55436	.83228	.56880	.82248	.58307	.81242	.59716	.80212	20
.55460	.83212	.56904	.82231	.58330	.81225	.59739	.80195	19
.55484	.83195	.56928	.82214	.58354	.81208	.59763	.80178	18
.55509	.83179	.56952	.82198	.58378	.81191	.59786	.80160	17
.55533	.83163	.56976	.82181	.58401	.81174	.59809	.80143	16
.55557	.83147	.57000	.82165	.58425	.81157	.59832	.80125	15
.55581	.83131	.57024	.82148	.58449	.81140	.59856	.80108	14
.55605	.83115	.57047	.82132	.58472	.81123	.59879	.80091	13
.55630	.83098	.57071	.82115	.58496	.81106	.59902	.80073	12
.55654	.83082	.57095	.82098	.58519	.81089	.59926	.80056	11
.55678	.83066	.57119	.82082	.58543	.81072	.59949	.80038	10
.55702	.83050	.57143	.82065	.58567	.81055	.59972	.80021	9
.55726	.83034	.57167	.82048	.58590	.81038	.59995	.80003	8
.55750	.83017	.57191	.82032	.58614	.81021	.60019	.79986	7
.55775	.83001	.57215	.82015	.58637	.81004	.60042	.79968	6
.55799	.82985	.57238	.81999	.58661	.80987	.60065	.79951	5
.55823	.82969	.57262	.81982	.58684	.80970	.60089	.79934	4
.55847	.82953	.57286	.81965	.58708	.80953	.60112	.79916	3
.55871	.82936	.57310	.81949	.58731	.80936	.60135	.79899	2
.55895	.82920	.57334	.81932	.58755	.80919	.60158	.79881	1
.55919	.82904	.57358	.81915	.58779	.80902	.60182	.79864	0
Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	′
56°		55°		54°		53°		

′	37° Sine	37° Cosine	38° Sine	38° Cosine	39° Sine	39° Cosine	40° Sine	40° Cosine	′
0	.60182	.79864	.61566	.78801	.62932	.77715	.64279	.76604	60
1	.60205	.79846	.61589	.78783	.62955	.77696	.64301	.76586	59
2	.60228	.79829	.61612	.78765	.62977	.77678	.64323	.76567	58
3	.60251	.79811	.61635	.78747	.63000	.77660	.64346	.76548	57
4	.60274	.79793	.61658	.78729	.63022	.77641	.64368	.76530	56
5	.60298	.79776	.61681	.78711	.63045	.77623	.64390	.76511	55
6	.60321	.79758	.61704	.78694	.63068	.77605	.64412	.76492	54
7	.60344	.79741	.61726	.78676	.63090	.77586	.64435	.76473	53
8	.60367	.79723	.61749	.78658	.63113	.77568	.64457	.76455	52
9	.60390	.79706	.61772	.78640	.63135	.77550	.64479	.76436	51
10	.60414	.79688	.61795	.78622	.63158	.77531	.64501	.76417	50
11	.60437	.79671	.61818	.78604	.63180	.77513	.64524	.76398	49
12	.60460	.79653	.61841	.78586	.63203	.77494	.64546	.76380	48
13	.60483	.79635	.61864	.78568	.63225	.77476	.64568	.76361	47
14	.60506	.79618	.61887	.78550	.63248	.77458	.64590	.76342	46
15	.60529	.79600	.61909	.78532	.63271	.77439	.64612	.76323	45
16	.60553	.79583	.61932	.78514	.63293	.77421	.64635	.76304	44
17	.60576	.79565	.61955	.78496	.63316	.77402	.64657	.76286	43
18	.60599	.79547	.61978	.78478	.63338	.77384	.64679	.76267	42
19	.60622	.79530	.62001	.78460	.63361	.77366	.64701	.76248	41
20	.60645	.79512	.62024	.78442	.63383	.77347	.64723	.76229	40
21	.60668	.79494	.62046	.78424	.63406	.77329	.64746	.76210	39
22	.60691	.79477	.62069	.78405	.63428	.77310	.64768	.76192	38
23	.60714	.79459	.62092	.78387	.63451	.77292	.64790	.76173	37
24	.60738	.79441	.62115	.78369	.63473	.77273	.64812	.76154	36
25	.60761	.79424	.62138	.78351	.63496	.77255	.64834	.76135	35
26	.60784	.79406	.62160	.78333	.63518	.77236	.64856	.76116	34
27	.60807	.79388	.62183	.78315	.63540	.77218	.64878	.76097	33
28	.60830	.79371	.62206	.78297	.63563	.77199	.64901	.76078	32
29	.60853	.79353	.62229	.78279	.63585	.77181	.64923	.76059	31
30	.60876	.79335	.62251	.78261	.63608	.77162	.64945	.76041	30
31	.60899	.79318	.62274	.78243	.63630	.77144	.64967	.76022	29
32	.60922	.79300	.62297	.78225	.63653	.77125	.64989	.76003	28
33	.60945	.79282	.62320	.78206	.63675	.77107	.65011	.75984	27
34	.60968	.79264	.62342	.78188	.63698	.77088	.65033	.75965	26
35	.60991	.79247	.62365	.78170	.63720	.77070	.65055	.75946	25
36	.61015	.79229	.62388	.78152	.63742	.77051	.65077	.75927	24
37	.61038	.79211	.62411	.78134	.63765	.77033	.65100	.75908	23
38	.61061	.79193	.62433	.78116	.63787	.77014	.65122	.75889	22
39	.61084	.79176	.62456	.78098	.63810	.76996	.65144	.75870	21
40	.61107	.79158	.62479	.78079	.63832	.76977	.65166	.75851	20
41	.61130	.79140	.62502	.78061	.63854	.76959	.65188	.75832	19
42	.61153	.79122	.62524	.78043	.63877	.76940	.65210	.75813	18
43	.61176	.79105	.62547	.78025	.63899	.76921	.65232	.75794	17
44	.61199	.79087	.62570	.78007	.63922	.76903	.65254	.75775	16
45	.61222	.79069	.62592	.77988	.63944	.76884	.65276	.75756	15
46	.61245	.79051	.62615	.77970	.63966	.76866	.65298	.75738	14
47	.61268	.79033	.62638	.77952	.63989	.76847	.65320	.75719	13
48	.61291	.79016	.62660	.77934	.64011	.76828	.65342	.75700	12
49	.61314	.78998	.62683	.77916	.64033	.76810	.65364	.75680	11
50	.61337	.78980	.62706	.77897	.64056	.76791	.65386	.75661	10
51	.61360	.78962	.62728	.77879	.64078	.76772	.65408	.75642	9
52	.61383	.78944	.62751	.77861	.64100	.76754	.65430	.75623	8
53	.61406	.78926	.62774	.77843	.64123	.76735	.65452	.75604	7
54	.61429	.78908	.62796	.77824	.64145	.76717	.65474	.75585	6
55	.61451	.78891	.62819	.77806	.64167	.76698	.65496	.75566	5
56	.61474	.78873	.62842	.77788	.64190	.76679	.65518	.75547	4
57	.61497	.78855	.62864	.77769	.64212	.76661	.65540	.75528	3
58	.61520	.78837	.62887	.77751	.64234	.76642	.65562	.75509	2
59	.61543	.78819	.62909	.77733	.64256	.76623	.65584	.75490	1
60	.61566	.78801	.62932	.77715	.64279	.76604	.65606	.75471	0
′	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	′
	52°		51°		50°		49°		

	41°		42°		43°		44°		
	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	′
0	.65606	.75471	.66913	.74314	.68200	.73135	.69466	.71934	60
1	.65628	.75452	.66935	.74295	.68221	.73116	.69487	.71914	59
2	.65650	.75433	.66956	.74276	.68242	.73096	.69508	.71894	58
3	.65672	.75414	.66978	.74256	.68264	.73076	.69529	.71873	57
4	.65694	.75395	.66999	.74237	.68285	.73056	.69549	.71853	56
5	.65716	.75375	.67021	.74217	.68306	.73036	.69570	.71833	55
6	.65738	.75356	.67043	.74198	.68327	.73016	.69591	.71813	54
7	.65759	.75337	.67064	.74178	.68349	.72996	.69612	.71792	53
8	.65781	.75318	.67086	.74159	.68370	.72976	.69633	.71772	52
9	.65803	.75299	.67107	.74139	.68391	.72957	.69654	.71752	51
10	.65825	.75280	.67129	.74120	.68412	.72937	.69675	.71732	50
11	.65847	.75261	.67151	.74100	.68434	.72917	.69696	.71711	49
12	.65869	.75241	.67172	.74080	.68455	.72897	.69717	.71691	48
13	.65891	.75222	.67194	.74061	.68476	.72877	.69737	.71671	47
14	.65913	.75203	.67215	.74041	.68497	.72857	.69758	.71650	46
15	.65935	.75184	.67237	.74022	.68518	.72837	.69779	.71630	45
16	.65956	.75165	.67258	.74002	.68539	.72817	.69800	.71610	44
17	.65978	.75146	.67280	.73983	.68561	.72797	.69821	.71590	43
18	.66000	.75126	.67301	.73963	.68582	.72777	.69842	.71569	42
19	.66022	.75107	.67323	.73944	.68603	.72757	.69862	.71549	41
20	.66044	.75088	.67344	.73924	.68624	.72737	.69883	.71529	40
21	.66066	.75069	.67366	.73904	.68645	.72717	.69904	.71508	39
22	.66088	.75050	.67387	.73885	.68666	.72697	.69925	.71488	38
23	.66109	.75030	.67409	.73865	.68688	.72677	.69946	.71468	37
24	.66131	.75011	.67430	.73846	.68709	.72657	.69966	.71447	36
25	.66153	.74992	.67452	.73826	.68730	.72637	.69987	.71427	35
26	.66175	.74973	.67473	.73806	.68751	.72617	.70008	.71407	34
27	.66197	.74953	.67495	.73787	.68772	.72597	.70029	.71386	33
28	.66218	.74934	.67516	.73767	.68793	.72577	.70049	.71366	32
29	.66240	.74915	.67538	.73747	.68814	.72557	.70070	.71345	31
30	.66262	.74896	.67559	.73728	.68835	.72537	.70091	.71325	30
31	.66284	.74876	.67580	.73708	.68857	.72517	.70112	.71305	29
32	.66306	.74857	.67602	.73688	.68878	.72497	.70132	.71284	28
33	.66327	.74838	.67623	.73669	.68899	.72477	.70153	.71264	27
34	.66349	.74818	.67645	.73649	.68920	.72457	.70174	.71243	26
35	.66371	.74799	.67666	.73629	.68941	.72437	.70195	.71223	25
36	.66393	.74780	.67688	.73610	.68962	.72417	.70215	.71203	24
37	.66414	.74760	.67709	.73590	.68983	.72397	.70236	.71182	23
38	.66436	.74741	.67730	.73570	.69004	.72377	.70257	.71162	22
39	.66458	.74722	.67752	.73551	.69025	.72357	.70277	.71141	21
40	.66480	.74703	.67773	.73531	.69046	.72337	.70298	.71121	20
41	.66501	.74683	.67795	.73511	.69067	.72317	.70319	.71100	19
42	.66523	.74664	.67816	.73491	.69088	.72297	.70339	.71080	18
43	.66545	.74644	.67837	.73472	.69109	.72277	.70360	.71059	17
44	.66566	.74625	.67859	.73452	.69130	.72257	.70381	.71039	16
45	.66588	.74606	.67880	.73432	.69151	.72236	.70401	.71019	15
46	.66610	.74586	.67901	.73413	.69172	.72216	.70422	.70998	14
47	.66632	.74567	.67923	.73393	.69193	.72196	.70443	.70978	13
48	.66653	.74548	.67944	.73373	.69214	.72176	.70463	.70957	12
49	.66675	.74528	.67965	.73353	.69235	.72156	.70484	.70937	11
50	.66697	.74509	.67987	.73333	.69256	.72136	.70505	.70916	10
51	.66718	.74489	.68008	.73314	.69277	.72116	.70525	.70896	9
52	.66740	.74470	.68029	.73294	.69298	.72095	.70546	.70875	8
53	.66762	.74451	.68051	.73274	.69319	.72075	.70567	.70855	7
54	.66783	.74431	.68072	.73254	.69340	.72055	.70587	.70834	6
55	.66805	.74412	.68093	.73234	.69361	.72035	.70608	.70813	5
56	.66827	.74392	.68115	.73215	.69382	.72015	.70628	.70793	4
57	.66848	.74373	.68136	.73195	.69403	.71995	.70649	.70772	3
58	.66870	.74353	.68157	.73175	.69424	.71974	.70670	.70752	2
59	.66891	.74334	.68179	.73155	.69445	.71954	.70690	.70731	1
60	.66913	.74314	.68200	.73135	.69466	.71934	.70711	.70711	0
′	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	′
	48°		47°		46°		45°		

′	0° Sec.	0° Co-sec.	1° Sec.	1° Co-sec.	2° Sec.	2° Co-sec.	3° Sec.	3° Co-sec.	′
0	1	Infinite.	1.0001	57.299	1.0006	28.654	1.0014	19.107	60
1	1	3437.70	1.0001	56.359	1.0006	28.417	1.0014	19.002	59
2	1	1718.90	1.0002	55.450	1.0006	28.184	1.0014	18.897	58
3	1	1145.90	1.0002	54.570	1.0006	27.955	1.0014	18.794	57
4	1	859.44	1.0002	53.718	1.0006	27.730	1.0014	18.692	56
5	1	687.55	1.0002	52.891	1.0007	27.508	1.0014	18.591	55
6	1	572.96	1.0002	52.090	1.0007	27.290	1.0015	18.491	54
7	1	491.11	1.0002	51.313	1.0007	27.075	1.0015	18.393	53
8	1	429.72	1.0002	50.558	1.0007	26.864	1.0015	18.295	52
9	1	381.97	1.0002	49.826	1.0007	26.655	1.0015	18.198	51
10	1	343.77	1.0002	49.114	1.0007	26.450	1.0015	18.103	50
11	1	312.52	1.0002	48.422	1.0007	26.249	1.0015	18.008	49
12	1	286.48	1.0002	47.750	1.0007	26.050	1.0016	17.914	48
13	1	264.44	1.0002	47.096	1.0007	25.854	1.0016	17.821	47
14	1	245.55	1.0002	46.460	1.0008	25.661	1.0016	17.730	46
15	1	229.18	1.0002	45.840	1.0008	25.471	1.0016	17.639	45
16	1	214.86	1.0002	45.237	1.0008	25.284	1.0016	17.549	44
17	1	202.22	1.0002	44.650	1.0008	25.100	1.0016	17.460	43
18	1	190.99	1.0002	44.077	1.0008	24.918	1.0017	17.372	42
19	1	180.73	1.0003	43.520	1.0008	24.739	1.0017	17.285	41
20	1	171.89	1.0003	42.976	1.0008	24.562	1.0017	17.198	40
21	1	163.70	1.0003	42.445	1.0008	24.358	1.0017	17.113	39
22	1	156.26	1.0003	41.928	1.0008	24.216	1.0017	17.028	38
23	1	149.47	1.0003	41.423	1 0009	24.047	1.0017	16.944	37
24	1	143.24	1.0003	40.930	1.0009	23.880	1.0018	16.861	36
25	1	137.51	1.0003	40.448	1.0009	23.716	1.0018	16.779	35
26	1	132.22	1.0003	39.978	1.0009	23.553	1.0018	16.698	34
27	1	127.32	1.0003	39.518	1.0009	23.393	1.0018	16.617	33
28	1	122.78	1.0003	39.069	1.0009	23.235	1.0018	16.538	32
29	1	118.54	1.0003	38.631	1.0009	23.079	1.0018	16.459	31
30	1	114.59	1.0003	38.201	1.0009	22.925	1.0019	16.380	30
31	1	110.90	1.0003	37.782	1.0010	22.774	1.0019	16.303	29
32	1	107.43	1.0003	37.371	1.0010	22.624	1.0019	16.226	28
33	1	104.17	1.0004	36.969	1.0010	22.476	1.0019	16.150	27
34	1	101.11	1.0004	36.576	1.0010	22.330	1.0019	16.075	26
35	1	98.223	1.0004	36.191	1.0010	22.186	1.0019	16.000	25
36	1	95.495	1.0004	35.814	1.0010	22.044	1.0020	15.926	24
37	1	92.914	1.0004	35.445	1.0010	21.904	1.0020	15.853	23
38	1.0001	92.469	1.0004	35.084	1.0010	21.765	1.0020	15.780	22
39	1.0001	88.149	1.0004	34.729	1.0011	21.629	1.0020	15.708	21
40	1.0001	85.946	1.0004	34.382	1.0011	21.494	1.0020	15.637	20
41	1.0001	83.849	1.0004	34.042	1.0011	21.360	1.0021	15.566	19
42	1.0001	81.853	1.0004	33.708	1.0011	21.228	1.0021	15.496	18
43	1.0001	79.950	1.0004	33.381	1.0011	21.098	1.0021	15.427	17
44	1.0001	78.133	1.0004	33.060	1.0011	20.970	1.0021	15.358	16
45	1.0001	76.396	1.0005	32.745	1.0011	20.843	1.0021	15.290	15
46	1.0001	74.736	1.0005	32.437	1.0012	20.717	1.0022	15.222	14
47	1.0001	73.146	1.0005	32.134	1.0012	20.593	1.0022	15.155	13
48	1.0001	71.622	1.0005	31.836	1.0012	20.471	1.0022	15.089	12
49	1.0001	71.160	1.0005	31.544	1.0012	20.350	1.0022	15.023	11
50	1.0001	68.757	1.0005	31.257	1.0012	20.230	1.0022	14.958	10
51	1.0001	67.409	1.0005	30.976	1.0012	20.112	1.0023	14.893	9
52	1.0001	66.113	1.0005	30.699	1.0012	19.995	1.0023	14.829	8
53	1.0001	64.866	1.0005	30.428	1.0013	19.880	1.0023	14.765	7
54	1.0001	63.664	1.0005	30.161	1.0013	19.766	1.0023	14.702	6
55	1.0001	62.507	1.0005	29.899	1.0013	19.653	1.0023	14.640	5
56	1.0001	61.391	1.0006	29.641	1.0013	19.541	1.0024	14.578	4
57	1.0001	61.314	1.0006	29.388	1.0013	19.431	1.0024	14.517	3
58	1.0001	59.274	1.0006	29.139	1.0013	19.322	1.0024	14.456	2
59	1.0001	58.270	1.0006	28.894	1.0013	19.214	1.0024	14.395	1
60	1.0001	57.299	1.0006	28.654	1.0014	19.107	1.0024	14.335	0
′	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	
	89°		88°		87°		86°		

4° Sec.	4° Co-sec.	5° Sec.	5° Co-sec.	6° Sec.	6° Co-sec.	7° Sec.	7° Co-sec.	′
1.0024	14.335	1.0038	11.474	1.0055	9.5668	1.0075	8.2055	60
1.0025	14.276	1.0038	11.436	1.0055	9.5404	1.0075	8.1861	59
1.0025	14.217	1.0039	11.398	1.0056	9.5141	1.0076	8.1668	58
1.0025	14.159	1.0039	11.360	1.0056	9.4880	1.0076	8.1476	57
1.0025	14.101	1.0039	11.323	1.0056	9.4620	1.0076	8.1285	56
1.0025	14.043	1.0039	11.286	1.0057	9.4362	1.0077	8.1094	55
1.0026	13.986	1.0040	11.249	1.0057	9.4105	1.0077	8.0905	54
1.0026	13.930	1.0040	11.213	1.0057	9.3850	1.0078	8.0717	53
1.0026	13.874	1.0040	11.176	1.0057	9.3596	1.0078	8.0529	52
1.0026	13.818	1.0040	11.140	1.0058	9.3343	1.0078	8.0342	51
1.0026	13.763	1.0041	11.104	1.0058	9.3092	1.0079	8.0156	50
1.0027	13.708	1.0041	11.069	1.0058	9.2842	1.0079	7.9971	49
1.0027	13.654	1.0041	11.033	1.0059	9.2593	1.0079	7.9787	48
1.0027	13.600	1.0041	10.988	1.0059	9.2346	1.0080	7.9604	47
1.0027	13.547	1.0042	10.963	1.0059	9.2100	1.0080	7.9421	46
1.0027	13.494	1.0042	10.929	1.0060	9.1855	1.0080	7.9240	45
1.0028	13.441	1.0042	10.894	1.0060	9.1612	1.0081	7.9059	44
1.0028	13.389	1.0043	10.860	1.0060	9.1370	1.0081	7.8879	43
1.0028	13.337	1.0043	10.826	1.0061	9.1129	1.0082	7.8700	42
1.0028	13.286	1.0043	10.792	1.0061	9.0890	1.0082	7.8522	41
1.0029	13.235	1.0043	10.758	1.0061	9.0651	1.0082	7.8344	40
1.0029	13.184	1.0044	10.725	1.0062	9.0414	1.0083	7.8168	39
1.0029	13.134	1.0044	10.692	1 0062	9.0179	1.0083	7.7992	38
1.0029	13.084	1.0044	10.659	1.0062	8.9944	1.0084	7.7817	37
1.0029	13.034	1.0044	10.626	1.0063	8.9711	1.0084	7.7642	36
1.0030	12.985	1.0045	10.593	1.0063	8.9479	1.0084	7.7469	35
1.0030	12.937	1.0045	10.561	1.0063	8.9248	1.0085	7.7296	34
1.0030	12.888	1.0045	10.529	1.0064	8.9018	1.0085	7.7124	33
1.0030	12.840	1.0046	10.497	1.0064	8.8790	1.0085	7.6953	32
1.0031	12.793	1.0046	10.465	1.0064	8.8563	1.0086	7.6783	31
1.0031	12.745	1.0046	10.433	1.0065	8.8337	1.0086	7.6613	30
1.0031	12.698	1.0046	10.402	1.0065	8.8112	1.0087	7.6444	29
1.0031	12.652	1.0047	10.371	1.0065	8.7888	1.0087	7.6276	28
1.0032	12.606	1.0047	10.340	1.0066	8.7665	1.0087	7.6108	27
1.0032	12.560	1.0047	10.309	1.0066	8.7444	1.0088	7.5942	26
1.0032	12.514	1.0048	10.278	1.0066	8.7223	1.0088	7.5776	25
1.0032	12.469	1.0048	10.248	1.0067	8.7004	1.0089	7.5611	24
1.0032	12.424	1.0048	10.217	1.0067	8.6786	1.0089	7.5446	23
1.0033	12.379	1.0048	10.187	1.0067	8.6569	1.0089	7.5282	22
1.0033	12.335	1.0049	10.157	1.0068	8.6353	1.0090	7.5119	21
1.0033	12.291	1.0049	10.127	1.0068	8.6138	1'0090	7.4957	20
1.0033	12.248	1.0049	10.098	1.0068	8.5924	1.0090	7.4795	19
1.0034	12.204	1.0050	10.068	1.0069	8.5711	1.0091	7.4634	18
1.0034	12.161	1.0050	10.039	1.0069	8.5499	1.0091	7.4474	17
1.0034	12.118	1.0050	10.010	1.0069	8.5289	1.0092	7.4315	16
1.0034	12.076	1.0050	9.9812	1.0070	8.5079	1.0092	7.4156	15
1.0035	12.034	1.0051	9.9525	1.0070	8.4871	1.0092	7.3998	14
1.0035	11.992	1.0051	9.9239	1.0070	8.4663	1.0093	7.3840	13
1.0035	11.950	1.0051	9.8955	1.0071	8.4457	1.0093	7.3683	12
1.0035	11.909	1.0052	9.8672	1.0071	8.4251	1.0094	7.3527	11
1.0036	11.868	1.0052	9.8391	1.0071	8.4046	1.0094	7.3372	10
1.0036	11.828	1.0052	9.8112	1.0072	8.3843	1.0094	7.3217	9
1.0036	11.787	1.0053	9.7834	1.0072	8.3640	1.0095	7.3063	8
1.0036	11.747	1.0053	9.7558	1.0073	8.3439	1.0095	7.2909	7
1.0037	11.707	1.0053	9.7283	1.0073	8.3238	1.0096	7.2757	6
1.0037	11.668	1.0053	9.7010	1.0073	8.3039	1.0096	7.2604	5
1.0037	11.628	1.0054	9.6739	1.0074	8.2840	1.0097	7.2453	4
1.0037	11.589	1.0054	9.6469	1.0074	8.2642	1.0097	7.2302	3
1.0038	11.550	1.0054	9.6200	1.0074	8.2446	1.0097	7.2152	2
1.0038	11.512	1.0055	9.5933	1.0075	8.2250	1.0098	7.2002	1
1.0038	11.474	1.0055	9.5668	1.0075	8.2055	1.0098	7.1853	0
Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	′
85°		84°		83°		82°		

′	13° Sine	13° Cosine	14° Sine	14° Cosine	15° Sine	15° Cosine	16° Sine	16° Cosine	′
0	.22495	.97437	.24192	.97030	.25882	.96593	.27564	.96126	60
1	.22523	.97430	.24220	.97023	.25910	.96585	.27592	.96118	59
2	.22552	.97424	.24249	.97015	.25938	.96578	.27620	.96110	58
3	.22580	.97417	.24277	.97008	.25966	.96570	.27648	.96102	57
4	.22608	.97411	.24305	.97001	.25994	.96562	.27676	.96094	56
5	.22637	.97404	.24333	.96994	.26022	.96555	.27704	.96086	55
6	.22665	.97398	.24362	.96987	.26050	.96547	.27731	.96078	54
7	.22693	.97391	.24390	.96980	.26079	.96540	.27759	.96070	53
8	.22722	.97384	.24418	.96973	.26107	.96532	.27787	.96062	52
9	.22750	.97378	.24446	.96966	.26135	.96524	.27815	.96054	51
10	.22778	.97371	.24474	.96959	.26163	.96517	.27843	.96046	50
11	.22807	.97365	.24503	.96952	.26191	.96509	.27871	.96037	49
12	.22835	.97358	.24531	.96945	.26219	.96502	.27899	.96029	48
13	.22863	.97351	.24559	.96937	.26247	.96494	.27927	.96021	47
14	.22892	.97345	.24587	.96930	.26275	.96486	.27955	.96013	46
15	.22920	.97338	.24615	.96923	.26303	.96479	.27983	.96005	45
16	.22948	.97331	.24644	.96916	.26331	.96471	.28011	.95997	44
17	.22977	.97325	.24672	.96909	.26359	.96463	.28039	.95989	43
18	.23005	.97318	.24700	.96902	.26387	.96456	.28067	.95981	42
19	.23033	.97311	.24728	.96894	.26415	.96448	.28095	.95972	41
20	.23062	.97304	.24756	.96887	.26443	.96440	.28123	.95964	40
21	.23090	.97298	.24784	.96880	.26471	.96433	.28150	.95956	39
22	.23118	.97291	.24813	.96873	.26500	.96425	.28178	.95948	38
23	.23146	.97284	.24841	.96866	.26528	.96417	.28206	.95940	37
24	.23175	.97278	.24869	.96858	.26556	.96410	.28234	.95931	36
25	.23203	.97271	.24897	.96851	.26584	.96402	.28262	.95923	35
26	.23231	.97264	.24925	.96844	.26612	.96394	.28290	.95915	34
27	.23260	.97257	.24954	.96837	.26640	.96386	.28318	.95907	33
28	.23288	.97251	.24982	.96829	.26668	.96379	.28346	.95898	32
29	.23316	.97244	.25010	.96822	.26696	.96371	.28374	.95890	31
30	.23345	.97237	.25038	.96815	.26724	.96363	.28402	.95882	30
31	.23373	.97230	.25066	.96807	.26752	.96355	.28429	.95874	29
32	.23401	.97223	.25094	.96800	.26780	.96347	.28457	.95865	28
33	.23429	.97217	.25122	.96793	.26808	.96340	.28485	.95857	27
34	.23458	.97210	.25151	.96786	.26836	.96332	.28513	.95849	26
35	.23486	.97203	.25179	.96778	.26864	.96324	.28541	.95841	25
36	.23514	.97196	.25207	.96771	.26892	.96316	.28569	.95832	24
37	.23542	.97189	.25235	.96764	.26920	.96308	.28597	.95824	23
38	.23571	.97182	.25263	.96756	.26948	.96301	.28625	.95816	22
39	.23599	.97176	.25291	.96749	.26976	.96293	.28652	.95807	21
40	.23627	.97169	.25320	.96742	.27004	.96285	.28680	.95799	20
41	.23656	.97162	.25348	.96734	.27032	.96277	.28708	.95791	19
42	.23684	.97155	.25376	.96727	.27060	.96269	.28736	.95782	18
43	.23712	.97148	.25404	.96719	.27088	.96261	.28764	.95774	17
44	.23740	.97141	.25432	.96712	.27116	.96253	.28792	.95766	16
45	.23769	.97134	.25460	.96705	.27144	.96246	.28820	.95757	15
46	.23797	.97127	.25488	.96697	.27172	.96238	.28847	.95749	14
47	.23825	.97120	.25516	.96690	.27200	.96230	.28875	.95740	13
48	.23853	.97113	.25545	.96682	.27228	.96222	.28903	.95732	12
49	.23882	.97106	.25573	.96675	.27256	.96214	.28931	.95724	11
50	.23910	.97100	.25601	.96667	.27284	.96206	.28959	.95715	10
51	.23938	.97093	.25629	.96660	.27312	.96198	.28987	.95707	9
52	.23966	.97086	.25657	.96653	.27340	.96190	.29015	.95698	8
53	.23995	.97079	.25685	.96645	.27368	.96182	.29042	.95690	7
54	.24023	.97072	.25713	.96638	.27396	.96174	.29070	.95681	6
55	.24051	.97065	.25741	.96630	.27424	.96166	.29098	.95673	5
56	.24079	.97058	.25769	.96623	.27452	.96158	.29126	.95664	4
57	.24108	.97051	.25798	.96615	.27480	.96150	.29154	.95656	3
58	.24136	.97044	.25826	.96608	.27508	.96142	.29182	.95647	2
59	.24164	.97037	.25854	.96600	.27536	.96134	.29209	.95639	1
60	.24192	.97030	.25882	.96593	.27564	.96126	.29237	.95630	0
′	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	′
	76°		75°		74°		73°		

17° Sine	17° Cosine	18° Sine	18° Cosine	19° Sine	19° Cosine	20° Sine	20° Cosine	′
.29237	.95630	.30902	.95106	.32557	.94552	.34202	.93969	60
.29265	.95622	.30929	.95097	.32584	.94542	.34229	.93959	59
.29293	.95613	.30957	.95088	.32612	.94533	.34257	.93949	58
.29321	.95605	.30985	.95079	.32639	.94523	.34284	.93939	57
.29348	.95596	.31012	.95070	.32667	.94514	.34311	.93929	56
.29376	.95588	.31040	.95061	.32694	.94504	.34339	.93919	55
.29404	.95579	.31068	.95052	.32722	.94495	.34367	.93909	54
.29432	.95571	.31095	.95043	.32749	.94485	.34393	.93899	53
.29460	.95562	.31123	.95033	.32777	.94476	.34421	.93889	52
.29487	.95554	.31151	.95024	.32804	.94466	.34448	.93879	51
.29515	.95545	.31178	.95015	.32832	.94457	.34475	.93869	50
.29543	.95536	.31206	.95006	.32859	.94447	.34503	.93859	49
.29571	.95528	.31233	.94997	.32887	.94438	.34530	.93849	48
.29599	.95519	.31261	.94988	.32914	.94428	.34557	.93839	47
.29626	.95511	.31289	.94979	.32942	.94418	.34584	.93829	46
.29654	.95502	.31316	.94970	.32969	.94409	.34612	.93819	45
.29682	.95493	.31344	.94961	.32997	.94399	.34639	.93809	44
.29710	.95485	.31372	.94952	.33024	.94390	.34666	.93799	43
.29737	.95476	.31399	.94943	.33051	.94380	.34694	.93789	42
.29765	.95467	.31427	.94933	.33079	.94370	.34721	.93779	41
.29793	.95459	.31454	.94924	.33106	.94361	.34748	.93769	40
.29821	.95450	.31482	.94915	.33134	.94351	.34775	.93759	39
.29849	.95441	.31510	.94906	.33161	.94342	.34803	.93748	38
.29876	.95433	.31537	.94897	.33189	.94332	.34830	.93738	37
.29904	.95424	.31565	.94888	.33216	.94322	.34857	.93728	36
.29932	.95415	.31593	.94878	.33244	.94313	.34884	.93718	35
.29960	.95407	.31620	.94869	.33271	.94303	.34912	.93708	34
.29987	.95398	.31648	.94860	.33298	.94293	.34939	.93698	33
.30015	.95389	.31675	.94851	.33326	.94284	.34966	.93688	32
.30043	.95380	.31703	.94842	.33353	.94274	.34993	.93677	31
.30071	.95372	.31730	.94832	.33381	.94264	.35021	.93667	30
.30098	.95363	.31758	.94823	.33408	.94254	.35048	.93657	29
.30126	.95354	.31786	.94814	.33436	.94245	.35075	.93647	28
.30154	.95345	.31813	.94805	.33463	.94235	.35102	.93637	27
.30182	.95337	.31841	.94795	.33490	.94225	.35130	.93626	26
.30209	.95328	.31868	.94786	.33518	.94215	.35157	.93616	25
.30237	.95319	.31896	.94777	.33545	.94206	.35184	.93606	24
.30265	.95310	.31923	.94768	.33573	.94196	.35211	.93596	23
.30292	.95301	.31951	.94758	.33600	.94186	.35239	.93585	22
.30320	.95293	.31979	.94749	.33627	.94176	.35266	.93575	21
.30348	.95284	.32006	.94740	.33655	.94167	.35293	.93565	20
.30376	.95275	.32034	.94730	.33682	.94157	.35320	.93555	19
.30403	.95266	.32061	.94721	.33710	.94147	.35347	.93544	18
.30431	.95257	.32089	.94712	.33737	.94137	.35375	.93534	17
.30459	.95248	.32116	.94702	.33764	.94127	.35402	.93524	16
.30486	.95240	.32144	.94693	.33792	.94118	.35429	.93514	15
.30514	.95231	.32171	.94684	.33819	.94108	.35456	.93503	14
.30542	.95222	.32199	.94674	.33846	.94098	.35484	.93493	13
.30570	.95213	.32227	.94665	.33874	.94088	.35511	.93483	12
.30597	.95204	.32254	.94656	.33901	.94078	.35538	.93472	11
.30625	.95195	.32282	.94646	.33929	.94068	.35565	.93462	10
.30653	.95186	.32309	.94637	.33956	.94058	.35592	.93452	9
.30680	.95177	.32337	.94627	.33983	.94049	.35619	.93441	8
.30708	.95168	.32364	.94618	.34011	.94039	.35647	.93431	7
.30736	.95159	.32392	.94609	.34038	.94029	.35674	.93420	6
.30763	.95150	.32419	.94599	.34065	.94019	.35701	.93410	5
.30791	.95142	.32447	.94590	.34093	.94009	.35728	.93400	4
.30819	.95133	.32474	.94580	.34120	.93999	.35755	.93389	3
.30846	.95124	.32502	.94571	.34147	.93989	.35782	.93379	2
.30874	.95115	.32529	.94561	.34175	.93979	.35810	.93368	1
.30902	.95106	.32557	.94552	.34202	.93969	.35837	.93358	0
Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	′
72°		71°		70°		69°		

′	21° Sine	21° Cosine	22° Sine	22° Cosine	23° Sine	23° Cosine	24° Sine	24° Cosine	′
0	.35837	.93358	.37461	.92718	.39073	.92050	.40674	.91355	60
1	.35864	.93348	.37488	.92707	.39100	.92039	.40700	.91343	59
2	.35891	.93337	.37515	.92697	.39127	.92028	.40727	.91331	58
3	.35918	.93327	.37542	.92686	.39153	.92016	.40753	.91319	57
4	.35945	.93316	.37569	.92675	.39180	.92005	.40780	.91307	56
5	.35973	.93306	.37595	.92664	.39207	.91994	.40806	.91295	55
6	.36000	.93295	.37622	.92653	.39234	.91982	.40833	.91283	54
7	.36027	.93285	.37649	.92642	.39260	.91971	.40860	.91272	53
8	.36054	.93274	.37676	.92631	.39287	.91959	.40886	.91260	52
9	.36081	.93264	.37703	.92620	.39314	.91948	.40913	.91248	51
10	.36108	.93253	.37730	.92609	.39341	.91936	.40939	.91236	50
11	.36135	.93243	.37757	.92598	.39367	.91925	.40966	.91224	49
12	.36162	.93232	.37784	.92587	.39394	.91914	.40992	.91212	48
13	.36190	.93222	.37811	.92576	.39421	.91902	.41019	.91200	47
14	.36217	.93211	.37838	.92565	.39448	.91891	.41045	.91188	46
15	.36244	.93201	.37865	.92554	.39474	.91879	.41072	.91176	45
16	.36271	.93190	.37892	.92543	.39501	.91868	.41098	.91164	44
17	.36298	.93180	.37919	.92532	.39528	.91856	.41125	.91152	43
18	.36325	.93169	.37946	.92521	.39555	.91845	.41151	.91140	42
19	.36352	.93159	.37973	.92510	.39581	.91833	.41178	.91128	41
20	.36379	.93148	.37999	.92499	.39608	.91822	.41204	.91116	40
21	.36406	.93137	.38026	.92488	.39635	.91810	.41231	.91104	39
22	.36434	.93127	.38053	.92477	.39661	.91799	.41257	.91092	38
23	.36461	.93116	.38080	.92466	.39688	.91787	.41284	.91080	37
24	.36488	.93106	.38107	.92455	.39715	.91775	.41310	.91068	36
25	.36515	.93095	.38134	.92444	.39741	.91764	.41337	.91056	35
26	.36542	.93084	.38161	.92432	.39768	.91752	.41363	.91044	34
27	.36569	.93074	.38188	.92421	.39795	.91741	.41390	.91032	33
28	.36596	.93063	.38215	.92410	.39822	.91729	.41416	.91020	32
29	.36623	.93052	.38241	.92399	.39848	.91718	.41443	.91008	31
30	.36650	.93042	.38268	.92388	.39875	.91706	.41469	.90996	30
31	.36677	.93031	.38295	.92377	.39902	.91694	.41496	.90984	29
32	.36704	.93020	.38322	.92366	.39928	.91683	.41522	.90972	28
33	.36731	.93010	.38349	.92355	.39955	.91671	.41549	.90960	27
34	.36758	.92999	.38376	.92343	.39982	.91660	.41575	.90948	26
35	.36785	.92988	.38403	.92332	.40008	.91648	.41602	.90936	25
36	.36812	.92978	.38430	.92321	.40035	.91636	.41628	.90924	24
37	.36839	.92967	.38456	.92310	.40062	.91625	.41655	.90911	23
38	.36867	.92956	.38483	.92299	.40088	.91613	.41681	.90899	22
39	.36894	.92945	.38510	.92287	.40115	.91601	.41707	.90887	21
40	.36921	.92935	.38537	.92276	.40141	.91590	.41734	.90875	20
41	.36948	.92924	.38564	.92265	.40168	.91578	.41760	.90863	19
42	.36975	.92913	.38591	.92254	.40195	.91566	.41787	.90851	18
43	.37002	.92902	.38617	.92243	.40221	.91555	.41813	.90839	17
44	.37029	.92892	.38644	.92231	.40248	.91543	.41840	.90826	16
45	.37056	.92881	.38671	.92220	.40275	.91531	.41866	.90814	15
46	.37083	.92870	.38698	.92209	.40301	.91519	.41892	.90802	14
47	.37110	.92859	.38725	.92198	.40328	.91508	.41919	.90790	13
48	.37137	.92849	.38752	.92186	.40355	.91496	.41945	.90778	12
49	.37164	.92838	.38778	.92175	.40381	.91484	.41972	.90766	11
50	.37191	.92827	.38805	.92164	.40408	.91472	.41998	.90753	10
51	.37218	.92816	.38832	.92152	.40434	.91461	.42024	.90741	9
52	.37245	.92805	.38859	.92141	.40461	.91449	.42051	.90729	8
53	.37272	.92794	.38886	.92130	.40488	.91437	.42077	.90717	7
54	.37299	.92784	.38912	.92119	.40514	.91425	.42104	.90704	6
55	.37326	.92773	.38939	.92107	.40541	.91414	.42130	.90692	5
56	.37353	.92762	.38966	.92096	.40567	.91402	.42156	.90680	4
57	.37380	.92751	.38993	.92085	.40594	.91390	.42183	.90668	3
58	.37407	.92740	.39020	.92073	.40621	.91378	.42209	.90655	2
59	.37434	.92729	.39046	.92062	.40647	.91366	.42235	.90643	1
60	.37461	.92718	.39073	.92050	.40674	.91355	.42262	.90631	0
′	68° Cosine	68° Sine	67° Cosine	67° Sine	66° Cosine	66° Sine	65° Cosine	65° Sine	′

25° Sine	25° Cosine	26° Sine	26° Cosine	27° Sine	27° Cosine	28° Sine	28° Cosine	′
.42262	.90631	.43837	.89879	.45399	.89101	.46947	.88295	60
.42288	.90618	.43863	.89867	.45425	.89087	.46973	.88281	59
.42315	.90606	.43889	.89854	.45451	.89074	.46999	.88267	58
.42341	.90594	.43916	.89841	.45477	.89061	.47024	.88254	57
.42367	.90582	.43942	.89828	.45503	.89048	.47050	.88240	56
.42394	.90569	.43968	.89816	.45529	.89035	.47076	.88226	55
.42420	.90557	.43994	.89803	.45554	.89021	.47101	.88213	54
.42446	.90545	.44020	.89790	.45580	.89008	.47127	.88199	53
.42473	.90532	.44046	.89777	.45606	.88995	.47153	.88185	52
.42499	.90520	.44072	.89764	.45632	.88981	.47178	.88172	51
.42525	.90507	.44098	.89752	.45658	.88968	.47204	.88158	50
.42552	.90495	.44124	.89739	.45684	.88955	.47229	.88144	49
.42578	.90483	.44151	.89726	.45710	.88942	.47255	.88130	48
.42604	.90470	.44177	.89713	.45736	.88928	.47281	.88117	47
.42631	.90458	.44203	.89700	.45762	.88915	.47306	.88103	46
.42657	.90446	.44229	.89687	.45787	.88902	.47332	.88089	45
.42683	.90433	.44255	.89674	.45813	.88888	.47358	.88075	44
.42709	.90421	.44281	.89662	.45839	.88875	.47383	.88062	43
.42736	.90408	.44307	.89649	.45865	.88862	.47409	.88048	42
.42762	.90396	.44333	.89636	.45891	.88848	.47434	.88034	41
.42788	.90383	.44359	.89623	.45917	.88835	.47460	.88020	40
.42815	.90371	.44385	.89610	.45942	.88822	.47486	.88006	39
.42841	.90358	.44411	.89597	.45968	.88808	.47511	.87993	38
.42867	.90346	.44437	.89584	.45994	.88795	.47537	.87979	37
.42894	.90334	.44464	.89571	.46020	.88782	.47562	.87965	36
.42920	.90321	.44490	.89558	.46046	.88768	.47588	.87951	35
.42946	.90309	.44516	.89545	.46072	.88755	.47614	.87937	34
.42972	.90296	.44542	.89532	.46097	.88741	.47639	.87923	33
.42999	.90284	.44568	.89519	.46123	.88728	.47665	.87909	32
.43025	.90271	.44594	.89506	.46149	.88715	.47690	.87896	31
.43051	.90259	.44620	.89493	.46175	.88701	.47716	.87882	30
.43077	.90246	.44646	.89480	.46201	.88688	.47741	.87868	29
.43104	.90233	.44672	.89467	.46226	.88674	.47767	.87854	28
.43130	.90221	.44698	.89454	.46252	.88661	.47793	.87840	27
.43156	.90208	.44724	.89441	.46278	.88647	.47818	.87826	26
.43182	.90196	.44750	.89428	.46304	.88634	.47844	.87812	25
.43209	.90183	.44776	.89415	.46330	.88620	.47869	.87798	24
.43235	.90171	.44802	.89402	.46355	.88607	.47895	.87784	23
.43261	.90158	.44828	.89389	.46381	.88593	.47920	.87770	22
.43287	.90146	.44854	.89376	.46407	.88580	.47946	.87756	21
.43313	.90133	.44880	.89363	.46433	.88566	.47971	.87743	20
.43340	.90120	.44906	.89350	.46458	.88553	.47997	.87729	19
.43366	.90108	.44932	.89337	.46484	.88539	.48022	.87715	18
.43392	.90095	.44958	.89324	.46510	.88526	.48048	.87701	17
.43418	.90082	.44984	.89311	.46536	.88512	.48073	.87687	16
.43445	.90070	.45010	.89298	.46561	.88499	.48099	.87673	15
.43471	.90057	.45036	.89285	.46587	.88485	.48124	.87659	14
.43497	.90045	.45062	.89272	.46613	.88472	.48150	.87645	13
.43523	.90032	.45088	.89259	.46639	.88458	.48175	.87631	12
.43549	.90019	.45114	.89245	.46664	.88445	.48201	.87617	11
.43575	.90007	.45140	.89232	.46690	.88431	.48226	.87603	10
.43602	.89994	.45166	.89219	.46716	.88417	.48252	.87589	9
.43628	.89981	.45192	.89206	.46742	.88404	.48277	.87575	8
.43654	.89968	.45218	.89193	.46767	.88390	.48303	.87561	7
.43680	.89956	.45243	.89180	.46793	.88377	.48328	.87546	6
.43706	.89943	.45269	.89167	.46819	.88363	.48354	.87532	5
.43733	.89930	.45295	.89153	.46844	.88349	.48379	.87518	4
.43759	.89918	.45321	.89140	.46870	.88336	.48405	.87504	3
.43785	.89905	.45347	.89127	.46896	.88322	.48430	.87490	2
.43811	.89892	.45373	.89114	.46921	.88308	.48456	.87476	1
.43837	.89879	.45399	.89101	.46947	.88295	.48481	.87462	0
Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	′
64°		63°		62°		61°		

′	29°		30°		31°		32°		′
	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	
0	.48481	.87462	.50000	.86603	.51504	.85717	.52992	.84805	60
1	.48506	.87448	.50025	.86588	.51529	.85702	.53017	.84789	59
2	.48532	.87434	.50050	.86573	.51554	.85687	.53041	.84774	58
3	.48557	.87420	.50076	.86559	.51579	.85672	.53066	.84759	57
4	.48583	.87406	.50101	.86544	.51604	.85657	.53091	.84743	56
5	.48608	.87391	.50126	.86530	.51628	.85642	.53115	.84728	55
6	.48634	.87377	.50151	.86515	.51653	.85627	.53140	.84712	54
7	.48659	.87363	.50176	.86501	.51678	.85612	.53164	.84697	53
8	.48684	.87349	.50201	.86486	.51703	.85597	.53189	.84681	52
9	.48710	.87335	.50227	.86471	.51728	.85582	.53214	.84666	51
10	.48735	.87321	.50252	.86457	.51753	.85567	.53238	.84650	50
11	.48761	.87306	.50277	.86442	.51778	.85551	.53263	.84635	49
12	.48786	.87292	.50302	.86427	.51803	.85536	.53288	.84619	48
13	.48811	.87278	.50327	.86413	.51828	.85521	.53312	.84604	47
14	.48837	.87264	.50352	.86398	.51852	.85506	.53337	.84588	46
15	.48862	.87250	.50377	.86384	.51877	.85491	.53361	.84573	45
16	.48888	.87235	.50403	.86369	.51902	.85476	.53386	.84557	44
17	.48913	.87221	.50428	.86354	.51927	.85461	.53411	.84542	43
18	.48938	.87207	.50453	.86340	.51952	.85446	.53435	.84526	42
19	.48964	.87193	.50478	.86325	.51977	.85431	.53460	.84511	41
20	.48989	.87178	.50503	.86310	.52002	.85416	.53484	.84495	40
21	.49014	.87164	.50528	.86295	.52026	.85401	.53509	.84480	39
22	.49040	.87150	.50553	.86281	.52051	.85385	.53534	.84464	38
23	.49065	.87136	.50578	.86266	.52076	.85370	.53558	.84448	37
24	.49090	.87121	.50603	.86251	.52101	.85355	.53583	.84433	36
25	.49116	.87107	.50628	.86237	.52126	.85340	.53607	.84417	35
26	.49141	.87093	.50654	.86222	.52151	.85325	.53632	.84402	34
27	.49166	.87079	.50679	.86207	.52175	.85310	.53656	.84386	33
28	.49192	.87064	.50704	.86192	.52200	.85294	.53681	.84370	32
29	.49217	.87050	.50729	.86178	.52225	.85279	.53705	.84355	31
30	.49242	.87036	.50754	.86163	.52250	.85264	.53730	.84339	30
31	.49268	.87021	.50779	.86148	.52275	.85249	.53754	.84324	29
32	.49293	.87007	.50804	.86133	.52299	.85234	.53779	.84308	28
33	.49318	.86993	.50829	.86119	.52324	.85218	.53804	.84292	27
34	.49344	.86978	.50854	.86104	.52349	.85203	.53828	.84277	26
35	.49369	.86964	.50879	.86089	.52374	.85188	.53853	.84261	25
36	.49394	.86949	.50904	.86074	.52399	.85173	.53877	.84245	24
37	.49419	.86935	.50929	.86059	.52423	.85157	.53902	.84230	23
38	.49445	.86921	.50954	.86045	.52448	.85142	.53926	.84214	22
39	.49470	.86906	.50979	.86030	.52473	.85127	.53951	.84198	21
40	.49495	.86892	.51004	.86015	.52498	.85112	.53975	.84182	20
41	.49521	.86878	.51029	.86000	.52522	.85096	.54000	.84167	19
42	.49546	.86863	.51054	.85985	.52547	.85081	.54024	.84151	18
43	.49571	.86849	.51079	.85970	.52572	.85066	.54049	.84135	17
44	.49596	.86834	.51104	.85956	.52597	.85051	.54073	.84120	16
45	.49622	.86820	.51129	.85941	.52621	.85035	.54097	.84104	15
46	.49647	.86805	.51154	.85926	.52646	.85020	.54122	.84088	14
47	.49672	.86791	.51179	.85911	.52671	.85005	.54146	.84072	13
48	.49697	.86777	.51204	.85896	.52696	.84989	.54171	.84057	12
49	.49723	.86762	.51229	.85881	.52720	.84974	.54195	.84041	11
50	.49748	.86748	.51254	.85866	.52745	.84959	.54220	.84025	10
51	.49773	.86733	.51279	.85851	.52770	.84943	.54244	.84009	9
52	.49798	.86719	.51304	.85836	.52794	.84928	.54269	.83994	8
53	.49824	.86704	.51329	.85821	.52819	.84913	.54293	.83978	7
54	.49849	.86690	.51354	.85806	.52844	.84897	.54317	.83962	6
55	.49874	.86675	.51379	.85792	.52869	.84882	.54342	.83946	5
56	.49899	.86661	.51404	.85777	.52893	.84866	.54366	.83930	4
57	.49924	.86646	.51429	.85762	.52918	.84851	.54391	.83915	3
58	.49950	.86632	.51454	.85747	.52943	.84836	.54415	.83899	2
59	.49975	.86617	.51479	.85732	.52967	.84820	.54440	.83883	1
60	.50000	.86603	.51504	.85717	.52992	.84805	.54464	.83867	0
′	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	′
	60°		59°		58°		57°		

33° Sine	33° Cosine	34° Sine	34° Cosine	35° Sine	35° Cosine	36° Sine	36° Cosine	′
.54464	.83867	.55919	.82904	.57358	.81915	.58779	.80902	60
.54488	.83851	.55943	.82887	.57381	.81899	.58802	.80885	59
.54513	.83835	.55968	.82871	.57405	.81882	.58826	.80867	58
.54537	.83819	.55992	.82855	.57429	.81865	.58849	.80850	57
.54561	.83804	.56016	.82839	.57453	.81848	.58873	.80833	56
.54586	.83788	.56040	.82822	.57477	.81832	.58896	.80816	55
.54610	.83772	.56064	.82806	.57501	.81815	.58920	.80799	54
.54635	.83756	.56088	.82790	.57524	.81798	.58943	.80782	53
.54659	.83740	.56112	.82773	.57548	.81782	.58967	.80765	52
.54683	.83724	.56136	.82757	.57572	.81765	.58990	.80748	51
.54708	.83708	.56160	.82741	.57596	.81748	.59014	.80730	50
.54732	.83692	.56184	.82724	.57619	.81731	.59037	.80713	49
.54756	.83676	.56208	.82708	.57643	.81714	.59061	.80696	48
.54781	.83660	.56232	.82692	.57667	.81698	.59084	.80679	47
.54805	.83645	.56256	.82675	.57691	.81681	.59108	.80662	46
.54829	.83629	.56280	.82659	.57715	.81664	.59131	.80644	45
.54854	.83613	.56305	.82643	.57738	.81647	.59154	.80627	44
.54878	.83597	.56329	.82626	.57762	.81631	.59178	.80610	43
.54902	.83581	.56353	.82610	.57786	.81614	.59201	.80593	42
.54927	.83565	.56377	.82593	.57810	.81597	.59225	.80576	41
.54951	.83549	.56401	.82577	.57833	.81580	.59248	.80558	40
.54975	.83533	.56425	.82561	.57857	.81563	.59272	.80541	39
.54999	.83517	.56449	.82544	.57881	.81546	.59295	.80524	38
.55024	.83501	.56473	.82528	.57904	.81530	.59318	.80507	37
.55048	.83485	.56497	.82511	.57928	.81513	.59342	.80489	36
.55072	.83469	.56521	.82495	.57952	.81496	.59365	.80472	35
.55097	.83453	.56545	.82478	.57976	.81479	.59389	.80455	34
.55121	.83437	.56569	.82462	.57999	.81462	.59412	.80438	33
.55145	.83421	.56593	.82446	.58023	.81445	.59436	.80420	32
.55169	.83405	.56617	.82429	.58047	.81428	.59459	.80403	31
.55194	.83389	.56641	.82413	.58070	.81412	.59482	.80386	30
.55218	.83373	.56665	.82396	.58094	.81395	.59506	.80368	29
.55242	.83356	.56689	.82340	.58118	.81378	.59529	.80351	28
.55266	.83340	.56713	.82363	.58141	.81361	.59552	.80334	27
.55291	.83324	.56736	.82347	.58165	.81344	.59576	.80316	26
.55315	.83308	.56760	.82330	.58189	.81327	.59599	.80299	25
.55339	.83292	.56784	.82314	.58212	.81310	.59622	.80282	24
.55363	.83276	.56808	.82297	.58236	.81293	.59646	.80264	23
.55388	.83260	.56832	.82281	.58260	.81276	.59669	.80247	22
.55412	.83244	.56856	.82264	.58283	.81259	.59693	.80230	21
.55436	.83228	.56880	.82248	.58307	.81242	.59716	.80212	20
.55460	.83212	.56904	.82231	.58330	.81225	.59739	.80195	19
.55484	.83195	.56928	.82214	.58354	.81208	.59763	.80178	18
.55509	.83179	.56952	.82198	.58378	.81191	.59786	.80160	17
.55533	.83163	.56976	.82181	.58401	.81174	.59809	.80143	16
.55557	.83147	.57000	.82165	.58425	.81157	.59832	.80125	15
.55581	.83131	.57024	.82148	.58449	.81140	.59856	.80108	14
.55605	.83115	.57047	.82132	.58472	.81123	.59879	.80091	13
.55630	.83098	.57071	.82115	.58496	.81106	.59902	.80073	12
.55654	.83082	.57095	.82098	.58519	.81089	.59926	.80056	11
.55678	.83066	.57119	.82082	.58543	.81072	.59949	.80038	10
.55702	.83050	.57143	.82065	.58567	.81055	.59972	.80021	9
.55726	.83034	.57167	.82048	.58590	.81038	.59995	.80003	8
.55750	.83017	.57191	.82032	.58614	.81021	.60019	.79986	7
.55775	.83001	.57215	.82015	.58637	.81004	.60042	.79968	6
.55799	.82985	.57238	.81999	.58661	.80987	.60065	.79951	5
.55823	.82969	.57262	.81982	.58684	.80970	.60089	.79934	4
.55847	.82953	.57286	.81965	.58708	.80953	.60112	.79916	3
.55871	.82936	.57310	.81949	.58731	.80936	.60135	.79899	2
.55895	.82920	.57334	.81932	.58755	.80919	.60158	.79881	1
.55919	.82904	.57358	.81915	.58779	.80902	.60182	.79864	0
Cosine 56°	Sine 56°	Cosine 55°	Sine 55°	Cosine 54°	Sine 54°	Cosine 53°	Sine 53°	′

′	37° Sine	37° Cosine	38° Sine	38° Cosine	39° Sine	39° Cosine	40° Sine	40° Cosine	′
0	.60182	.79864	.61566	.78801	.62932	.77715	.64279	.76604	60
1	.60205	.79846	.61589	.78783	.62955	.77696	.64301	.76586	59
2	.60228	.79829	.61612	.78765	.62977	.77678	.64323	.76567	58
3	.60251	.79811	.61635	.78747	.63000	.77660	.64346	.76548	57
4	.60274	.79793	.61658	.78729	.63022	.77641	.64368	.76530	56
5	.60298	.79776	.61681	.78711	.63045	.77623	.64390	.76511	55
6	.60321	.79758	.61704	.78694	.63068	.77605	.64412	.76492	54
7	.60344	.79741	.61726	.78676	.63090	.77586	.64435	.76473	53
8	.60367	.79723	.61749	.78658	.63113	.77568	.64457	.76455	52
9	.60390	.79706	.61772	.78640	.63135	.77550	.64479	.76436	51
10	.60414	.79688	.61795	.78622	.63158	.77531	.64501	.76417	50
11	.60437	.79671	.61818	.78604	.63180	.77513	.64524	.76398	49
12	.60460	.79653	.61841	.78586	.63203	.77494	.64546	.76380	48
13	.60483	.79635	.61864	.78568	.63225	.77476	.64568	.76361	47
14	.60506	.79618	.61887	.78550	.63248	.77458	.64590	.76342	46
15	.60529	.79600	.61909	.78532	.63271	.77439	.64612	.76323	45
16	.60553	.79583	.61932	.78514	.63293	.77421	.64635	.76304	44
17	.60576	.79565	.61955	.78496	.63316	.77402	.64657	.76286	43
18	.60599	.79547	.61978	.78478	.63338	.77384	.64679	.76267	42
19	.60622	.79530	.62001	.78460	.63361	.77366	.64701	.76248	41
20	.60645	.79512	.62024	.78442	.63383	.77347	.64723	.76229	40
21	.60668	.79494	.62046	.78424	.63406	.77329	.64746	.76210	39
22	.60691	.79477	.62069	.78405	.63428	.77310	.64768	.76192	38
23	.60714	.79459	.62092	.78387	.63451	.77292	.64790	.76173	37
24	.60738	.79441	.62115	.78369	.63473	.77273	.64812	.76154	36
25	.60761	.79424	.62138	.78351	.63496	.77255	.64834	.76135	35
26	.60784	.79406	.62160	.78333	.63518	.77236	.64856	.76116	34
27	.60807	.79388	.62183	.78315	.63540	.77218	.64878	.76097	33
28	.60830	.79371	.62206	.78297	.63563	.77199	.64901	.76078	32
29	.60853	.79353	.62229	.78279	.63585	.77181	.64923	.76059	31
30	.60876	.79335	.62251	.78261	.63608	.77162	.64945	.76041	30
31	.60899	.79318	.62274	.78243	.63630	.77144	.64967	.76022	29
32	.60922	.79300	.62297	.78225	.63653	.77125	.64989	.76003	28
33	.60945	.79282	.62320	.78206	.63675	.77107	.65011	.75984	27
34	.60968	.79264	.62342	.78188	.63698	.77088	.65033	.75965	26
35	.60991	.79247	.62365	.78170	.63720	.77070	.65055	.75946	25
36	.61015	.79229	.62388	.78152	.63742	.77051	.65077	.75927	24
37	.61038	.79211	.62411	.78134	.63765	.77033	.65100	.75908	23
38	.61061	.79193	.62433	.78116	.63787	.77014	.65122	.75889	22
39	.61084	.79176	.62456	.78098	.63810	.76996	.65144	.75870	21
40	.61107	.79158	.62479	.78079	.63832	.76977	.65166	.75851	20
41	.61130	.79140	.62502	.78061	.63854	.76959	.65188	.75832	19
42	.61153	.79122	.62524	.78043	.63877	.76940	.65210	.75813	18
43	.61176	.79105	.62547	.78025	.63899	.76921	.65232	.75794	17
44	.61199	.79087	.62570	.78007	.63922	.76903	.65254	.75775	16
45	.61222	.79069	.62592	.77988	.63944	.76884	.65276	.75756	15
46	.61245	.79051	.62615	.77970	.63966	.76866	.65298	.75738	14
47	.61268	.79033	.62638	.77952	.63989	.76847	.65320	.75719	13
48	.61291	.79016	.62660	.77934	.64011	.76828	.65342	.75700	12
49	.61314	.78998	.62683	.77916	.64033	.76810	.65364	.75680	11
50	.61337	.78980	.62706	.77897	.64056	.76791	.65386	.75661	10
51	.61360	.78962	.62728	.77879	.64078	.76772	.65408	.75642	9
52	.61383	.78944	.62751	.77861	.64100	.76754	.65430	.75623	8
53	.61406	.78926	.62774	.77843	.64123	.76735	.65452	.75604	7
54	.61429	.78908	.62796	.77824	.64145	.76717	.65474	.75585	6
55	.61451	.78891	.62819	.77806	.64167	.76698	.65496	.75566	5
56	.61474	.78873	.62842	.77788	.64190	.76679	.65518	.75547	4
57	.61497	.78855	.62864	.77769	.64212	.76661	.65540	.75528	3
58	.61520	.78837	.62887	.77751	.64234	.76642	.65562	.75509	2
59	.61543	.78819	.62909	.77733	.64256	.76623	.65584	.75490	1
60	.61566	.78801	.62932	.77715	.64279	.76604	.65606	.75471	0
′	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	′
	52°		51°		50°		49°		

41°		42°		43°		44°		
Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	′
.65606	.75471	.66913	.74314	.68200	.73135	.69466	.71934	60
.65628	.75452	.66935	.74295	.68221	.73116	.69487	.71914	59
.65650	.75433	.66956	.74276	.68242	.73096	.69508	.71894	58
.65672	.75414	.66978	.74256	.68264	.73076	.69529	.71873	57
.65694	.75395	.66999	.74237	.68285	.73056	.69549	.71853	56
.65716	.75375	.67021	.74217	.68306	.73036	.69570	.71833	55
.65738	.75356	.67043	.74198	.68327	.73016	.69591	.71813	54
.65759	.75337	.67064	.74178	.68349	.72996	.69612	.71792	53
.65781	.75318	.67086	.74159	.68370	.72976	.69633	.71772	52
.65803	.75299	.67107	.74139	.68391	.72957	.69654	.71752	51
.65825	.75280	.67129	.74120	.68412	.72937	.69675	.71732	50
.65847	.75261	.67151	.74100	.68434	.72917	.69696	.71711	49
.65869	.75241	.67172	.74080	.68455	.72897	.69717	.71691	48
.65891	.75222	.67194	.74061	.68476	.72877	.69737	.71671	47
.65913	.75203	.67215	.74041	.68497	.72857	.69758	.71650	46
.65935	.75184	.67237	.74022	.68518	.72837	.69779	.71630	45
.65956	.75165	.67258	.74002	.68539	.72817	.69800	.71610	44
.65978	.75146	.67280	.73983	.68561	.72797	.69821	.71590	43
.66000	.75126	.67301	.73963	.68582	.72777	.69842	.71569	42
.66022	.75107	.67323	.73944	.68603	.72757	.69862	.71549	41
.66044	.75088	.67344	.73924	.68624	.72737	.69883	.71529	40
.66066	.75069	.67366	.73904	.68645	.72717	.69904	.71508	39
.66088	.75050	.67387	.73885	.68666	.72697	.69925	.71488	38
.66109	.75030	.67409	.73865	.68688	.72677	.69946	.71468	37
.66131	.75011	.67430	.73846	.68709	.72657	.69966	.71447	36
.66153	.74992	.67452	.73826	.68730	.72637	.69987	.71427	35
.66175	.74973	.67473	.73806	.68751	.72617	.70008	.71407	34
.66197	.74953	.67495	.73787	.68772	.72597	.70029	.71386	33
.66218	.74934	.67516	.73767	.68793	.72577	.70049	.71366	32
.66240	.74915	.67538	.73747	.68814	.72557	.70070	.71345	31
.66262	.74896	.67559	.73728	.68835	.72537	.70091	.71325	30
.66284	.74876	.67580	.73708	.68857	.72517	.70112	.71305	29
.66306	.74857	.67602	.73688	.68878	.72497	.70132	.71284	28
.66327	.74838	.67623	.73669	.68899	.72477	.70153	.71264	27
.66349	.74818	.67645	.73649	.68920	.72457	.70174	.71243	26
.66371	.74799	.67666	.73629	.68941	.72437	.70195	.71223	25
.66393	.74780	.67688	.73610	.68962	.72417	.70215	.71203	24
.66414	.74760	.67709	.73590	.68983	.72397	.70236	.71182	23
.66436	.74741	.67730	.73570	.69004	.72377	.70257	.71162	22
.66458	.74722	.67752	.73551	.69025	.72357	.70277	.71141	21
.66480	.74703	.67773	.73531	.69046	.72337	.70298	.71121	20
.66501	.74683	.67795	.73511	.69067	.72317	.70319	.71100	19
.66523	.74664	.67816	.73491	.69088	.72297	.70339	.71080	18
.66545	.74644	.67837	.73472	.69109	.72277	.70360	.71059	17
.66566	.74625	.67859	.73452	.69130	.72257	.70381	.71039	16
.66588	.74606	.67880	.73432	.69151	.72236	.70401	.71019	15
.66610	.74586	.67901	.73413	.69172	.72216	.70422	.70998	14
.66632	.74567	.67923	.73393	.69193	.72196	.70443	.70978	13
.66653	.74548	.67944	.73373	.69214	.72176	.70463	.70957	12
.66675	.74528	.67965	.73353	.69235	.72156	.70484	.70937	11
.66697	.74509	.67987	.73333	.69256	.72136	.70505	.70916	10
.66718	.74489	.68008	.73314	.69277	.72116	.70525	.70896	9
.66740	.74470	.68029	.73294	.69298	.72095	.70546	.70875	8
.66762	.74451	.68051	.73274	.69319	.72075	.70567	.70855	7
.66783	.74431	.68072	.73254	.69340	.72055	.70587	.70834	6
.66805	.74412	.68093	.73234	.69361	.72035	.70608	.70813	5
.66827	.74392	.68115	.73215	.69382	.72015	.70628	.70793	4
.66848	.74373	.68136	.73195	.69403	.71995	.70649	.70772	3
.66870	.74353	.68157	.73175	.69424	.71974	.70670	.70752	2
.66891	.74334	.68179	.73155	.69445	.71954	.70690	.70731	1
.66913	.74314	.68200	.73135	.69466	.71934	.70711	.70711	0
Cosine	Sine	Cosine	Sine	Cosine	Sine	Cosine	Sine	′
48°		47°		46°		45°		

′	0° Sec.	0° Co-sec.	1° Sec.	1° Co-sec.	2° Sec.	2° Co-sec.	3° Sec.	3° Co-sec.	′
0	1	Infinite.	1.0001	57.299	1.0006	28.654	1.0014	19.107	60
1	1	3437.70	1.0001	56.359	1.0006	28.417	1.0014	19.002	59
2	1	1718.90	1.0002	55.450	1.0006	28.184	1.0014	18.897	58
3	1	1145.90	1.0002	54.570	1.0006	27.955	1.0014	18.794	57
4	1	859.44	1.0002	53.718	1.0006	27.730	1.0014	18.692	56
5	1	687.55	1.0002	52.891	1.0007	27.508	1.0014	18.591	55
6	1	572.96	1.0002	52.090	1.0007	27.290	1.0015	18.491	54
7	1	491.11	1.0002	51.313	1.0007	27.075	1.0015	18.393	53
8	1	429.72	1.0002	50.558	1.0007	26.864	1.0015	18.295	52
9	1	381.97	1.0002	49.826	1.0007	26.655	1.0015	18.198	51
10	1	343.77	1.0002	49.114	1.0007	26.450	1.0015	18.103	50
11	1	312.52	1.0002	48.422	1.0007	26.249	1.0015	18.008	49
12	1	286.48	1.0002	47.750	1.0007	26.050	1.0016	17.914	48
13	1	264.44	1.0002	47.096	1.0007	25.854	1.0016	17.821	47
14	1	245.55	1.0002	46.460	1.0008	25.661	1.0016	17.730	46
15	1	229.18	1.0002	45.840	1.0008	25.471	1.0016	17.639	45
16	1	214.86	1.0002	45.237	1.0008	25.284	1.0016	17.549	44
17	1	202.22	1.0002	44.650	1.0008	25.100	1.0016	17.460	43
18	1	190.99	1.0002	44.077	1.0008	24.918	1.0017	17.372	42
19	1	180.73	1.0003	43.520	1.0008	24.739	1.0017	17.285	41
20	1	171.89	1.0003	42.976	1.0008	24.562	1.0017	17.198	40
21	1	163.70	1.0003	42.445	1.0008	24.358	1.0017	17.113	39
22	1	156.26	1.0003	41.928	1.0008	24.216	1.0017	17.028	38
23	1	149.47	1.0003	41.423	1 0009	24.047	1.0017	16.944	37
24	1	143.24	1.0003	40.930	1.0009	23.880	1.0018	16.861	36
25	1	137.51	1.0003	40.448	1.0009	23.716	1.0018	16.779	35
26	1	132.22	1.0003	39.978	1.0009	23.553	1.0018	16.698	34
27	1	127.32	1.0003	39.518	1.0009	23.393	1.0018	16.617	33
28	1	122.78	1.0003	39.069	1.0009	23.235	1.0018	16.538	32
29	1	118.54	1.0003	38.631	1.0009	23.079	1.0018	16.459	31
30	1	114.59	1.0003	38.201	1.0009	22.925	1.0019	16.380	30
31	1	110.90	1.0003	37.782	1.0010	22.774	1.0019	16.303	29
32	1	107.43	1.0003	37.371	1.0010	22.624	1.0019	16.226	28
33	1	104.17	1.0004	36.969	1.0010	22.476	1.0019	16.150	27
34	1	101.11	1.0004	36.576	1.0010	22.330	1.0019	16.075	26
35	1	98.223	1.0004	36.191	1.0010	22.186	1.0019	16.000	25
36	1	95.495	1.0004	35.814	1.0010	22.044	1.0020	15.926	24
37	1	92.914	1.0004	35.445	1.0010	21.904	1.0020	15.853	23
38	1.0001	92.469	1.0004	35.084	1.0010	21.765	1.0020	15.780	22
39	1.0001	88.149	1.0004	34.729	1.0011	21.629	1.0020	15.708	21
40	1.0001	85.946	1.0004	34.382	1.0011	21.494	1.0020	15.637	20
41	1.0001	83.849	1.0004	34.042	1.0011	21.360	1.0021	15.566	19
42	1.0001	81.853	1.0004	33.708	1.0011	21.228	1.0021	15.496	18
43	1.0001	79.950	1.0004	33.381	1.0011	21.098	1.0021	15.427	17
44	1.0001	78.133	1.0004	33.060	1.0011	20.970	1.0021	15.358	16
45	1.0001	76.396	1.0005	32.745	1.0011	20.843	1.0021	15.290	15
46	1.0001	74.736	1.0005	32.437	1.0012	20.717	1.0022	15.222	14
47	1.0001	73.146	1.0005	32.134	1.0012	20.593	1.0022	15.155	13
48	1.0001	71.622	1.0005	31.836	1.0012	20.471	1.0022	15.089	12
49	1.0001	71.160	1.0005	31.544	1.0012	20.350	1.0022	15.023	11
50	1.0001	68.757	1.0005	31.257	1.0012	20.230	1.0022	14.958	10
51	1.0001	67.409	1.0005	30.976	1.0012	20.112	1.0023	14.893	9
52	1.0001	66.113	1.0005	30.699	1.0012	19.995	1.0023	14.829	8
53	1.0001	64.866	1.0005	30.428	1.0013	19.880	1.0023	14.765	7
54	1.0001	63.664	1.0005	30.161	1.0013	19.766	1.0023	14.702	6
55	1.0001	62.507	1.0005	29.899	1.0013	19.653	1.0023	14.640	5
56	1.0001	61.391	1.0006	29.641	1.0013	19.541	1.0024	14.578	4
57	1.0001	61.314	1.0006	29.388	1.0013	19.431	1.0024	14.517	3
58	1.0001	59.274	1.0006	29.139	1.0013	19.322	1.0024	14.456	2
59	1.0001	58.270	1.0006	28.894	1.0013	19.214	1.0024	14.305	1
60	1.0001	57.299	1.0006	28.654	1.0014	19.107	1.0024	14.335	0
′	89° Co-sec.	89° Sec.	88° Co-sec.	88° Sec.	87° Co-sec.	87° Sec.	86° Co-sec.	86° Sec.	′

′	4° Sec.	4° Co-sec.	5° Sec.	5° Co-sec.	6° Sec.	6° Co-sec.	7° Sec.	7° Co-sec.	′
0	1.0024	14.335	1.0038	11.474	1.0055	9.5668	1.0075	8.2055	60
1	1.0025	14.276	1.0038	11.436	1.0055	9.5404	1.0075	8.1861	59
2	1.0025	14.217	1.0039	11.398	1.0056	9.5141	1.0076	8.1668	58
3	1.0025	14.159	1.0039	11.360	1.0056	9.4880	1.0076	8.1476	57
4	1.0025	14.101	1.0039	11.323	1.0056	9.4620	1.0076	8.1285	56
5	1.0025	14.043	1.0039	11.286	1.0057	9.4362	1.0077	8.1094	55
6	1.0026	13.986	1.0040	11.249	1.0057	9.4105	1.0077	8.0905	54
7	1.0026	13.930	1.0040	11.213	1.0057	9.3850	1.0078	8.0717	53
8	1.0026	13.874	1.0040	11.176	1.0057	9.3596	1.0078	8.0529	52
9	1.0026	13.818	1.0040	11.140	1.0058	9.3343	1.0078	8.0342	51
10	1.0026	13.763	1.0041	11.104	1.0058	9.3092	1.0079	8.0156	50
11	1.0027	13.708	1.0041	11.069	1.0058	9.2842	1.0079	7.9971	49
12	1.0027	13.654	1.0041	11.033	1.0059	9.2593	1.0079	7.9787	48
13	1.0027	13.600	1.0041	10.988	1.0059	9.2346	1.0080	7.9604	47
14	1.0027	13.547	1.0042	10.963	1.0059	9.2100	1.0080	7.9421	46
15	1.0027	13.494	1.0042	10.929	1.0060	9.1855	1.0080	7.9240	45
16	1.0028	13.441	1.0042	10.894	1.0060	9.1612	1.0081	7.9059	44
17	1.0028	13.389	1.0043	10.860	1.0060	9.1370	1.0081	7.8879	43
18	1.0028	13.337	1.0043	10.826	1.0061	9.1129	1.0082	7.8700	42
19	1.0028	13.286	1.0043	10.792	1.0061	9.0890	1.0082	7.8522	41
20	1.0029	13.235	1.0043	10.758	1.0061	9.0651	1.0082	7.8344	40
21	1.0029	13.184	1.0044	10.725	1.0062	9.0414	1.0083	7.8168	39
22	1.0029	13.134	1.0044	10.692	1 0062	9.0179	1.0083	7.7992	38
23	1.0029	13.084	1.0044	10.659	1.0062	8.9944	1.0084	7.7817	37
24	1.0029	13.034	1.0044	10.626	1.0063	8.9711	1.0084	7.7642	36
25	1.0030	12.985	1.0045	10.593	1.0063	8.9479	1.0084	7.7469	35
26	1.0030	12.937	1.0045	10.561	1.0063	8.9248	1.0085	7.7296	34
27	1.0030	12.888	1.0045	10.529	1.0064	8.9018	1.0085	7.7124	33
28	1.0030	12.840	1.0046	10.497	1.0064	8.8790	1.0085	7.6953	32
29	1.0031	12.793	1.0046	10.465	1.0064	8.8563	1.0086	7.6783	31
30	1.0031	12.745	1.0046	10.433	1.0065	8.8337	1.0086	7.6613	30
31	1.0031	12.698	1.0046	10.402	1.0065	8.8112	1.0087	7.6444	29
32	1.0031	12.652	1.0047	10.371	1.0065	8.7888	1.0087	7.6276	28
33	1.0032	12.606	1.0047	10.340	1.0066	8.7665	1.0087	7.6108	27
34	1.0032	12.560	1.0047	10.309	1.0066	8.7444	1.0088	7.5942	26
35	1.0032	12.514	1.0048	10.278	1.0066	8.7223	1.0088	7.5776	25
36	1.0032	12.469	1.0048	10.248	1.0067	8.7004	1.0089	7.5611	24
37	1.0032	12.424	1.0048	10.217	1.0067	8.6786	1.0089	7.5446	23
38	1.0033	12.379	1.0048	10.187	1.0067	8.6569	1.0089	7.5282	22
39	1.0033	12.335	1.0049	10.157	1.0068	8.6353	1.0090	7.5119	21
40	1.0033	12.291	1.0049	10.127	1.0068	8.6138	1·0090	7.4957	20
41	1.0033	12.248	1.0049	10.098	1.0068	8.5924	1.0090	7.4795	19
42	1.0034	12.204	1.0050	10.068	1.0069	8.5711	1.0091	7.4634	18
43	1.0034	12.161	1.0050	10.039	1.0069	8.5499	1.0091	7.4474	17
44	1.0034	12.118	1.0050	10.010	1.0069	8.5289	1.0092	7.4315	16
45	1.0034	12.076	1.0050	9.9812	1.0070	8.5079	1.0092	7.4156	15
46	1.0035	12.034	1.0051	9.9525	1.0070	8.4871	1.0092	7.3998	14
47	1.0035	11.992	1.0051	9.9239	1.0070	8.4663	1.0093	7.3840	13
48	1.0035	11.950	1.0051	9.8955	1.0071	8.4457	1.0093	7.3683	12
49	1.0035	11.909	1.0052	9.8672	1.0071	8.4251	1.0094	7.3527	11
50	1.0036	11.868	1.0052	9.8391	1.0071	8.4046	1.0094	7.3372	10
51	1.0036	11.828	1.0052	9.8112	1.0072	8.3843	1.0094	7.3217	9
52	1.0036	11.787	1.0053	9.7834	1.0072	8.3640	1.0095	7.3063	8
53	1.0036	11.747	1.0053	9.7558	1.0073	8.3439	1.0095	7.2909	7
54	1.0037	11.707	1.0053	9.7283	1.0073	8.3238	1.0096	7.2757	6
55	1.0037	11.668	1.0053	9.7010	1.0073	8.3039	1.0096	7.2604	5
56	1.0037	11.628	1.0054	9.6739	1.0074	8.2840	1.0097	7.2453	4
57	1.0037	11.589	1.0054	9.6469	1.0074	8.2642	1.0097	7.2302	3
58	1.0038	11.550	1.0054	9.6200	1.0074	8.2446	1.0097	7.2152	2
59	1.0038	11.512	1.0055	9.5933	1.0075	8.2250	1.0098	7.2002	1
60	1.0038	11.474	1.0055	9.5668	1.0075	8.2055	1.0098	7.1853	0
′	85° Co-sec.	85° Sec.	84° Co-sec.	84° Sec.	83° Co-sec.	83° Sec.	82° Co-sec.	82° Sec.	′

	8°		9°		10°		11°		
′	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	′
0	1.0098	7.1853	1.0125	6.3924	1.0154	5.7588	1.0187	5.2408	60
1	1.0099	7.1704	1.0125	6.3807	1.0155	5.7493	1.0188	5.2330	59
2	1.0099	7.1557	1.0125	6.3690	1.0155	5.7398	1.0188	5.2252	58
3	1.0099	7.1409	1.0126	6.3574	1.0156	5.7304	1.0189	5.2174	57
4	1.0100	7.1263	1.0126	6.3458	1.0156	5.7210	1.0189	5.2097	56
5	1.0100	7.1117	1.0127	6.3343	1.0157	5.7117	1.0190	5.2019	55
6	1.0101	7.0972	1.0127	6.3228	1.0157	5.7023	1.0191	5.1942	54
7	1.0101	7.0827	1.0128	6.3113	1.0158	5.6930	1.0191	5.1865	53
8	1.0102	7.0683	1.0128	6.2999	1.0158	5.6838	1.0192	5.1788	52
9	1.0102	7.0539	1.0129	6.2885	1.0159	5.6745	1.0192	5.1712	51
10	1.0102	7.0396	1.0129	6.2772	1.0159	5.6653	1.0193	5.1636	50
11	1.0103	7.0254	1.0130	6.2659	1.0160	5.6561	1.0193	5.1560	49
12	1.0103	7.0112	1.0130	6.2546	1.0160	5.6470	1.0194	5.1484	48
13	1.0104	6.9971	1.0131	6.2434	1.0161	5.6379	1.0195	5.1409	47
14	1.0104	6.9830	1.0131	6.2322	1.0162	5.6288	1.0195	5.1333	46
15	1.0104	6.9690	1.0132	6.2211	1.0162	5.6197	1.0196	5.1258	45
16	1.0105	6.9550	1.0132	6.2100	1. 163	5.6107	1.0196	5.1183	44
17	1.0105	6.9411	1.0133	6.1990	1.0163	5.6017	1.0197	5.1109	43
18	1.0106	6.9273	1.0133	6.1880	1.0164	5.5928	1.0198	5.1034	42
19	1.0106	6.9135	1.0134	6.1770	1.0164	5.5838	1.0198	5.0960	41
20	1.0107	6.8998	1.0134	6.1661	1.0165	5.5749	1.0199	5.0886	40
21	1.0107	6.8861	1.0135	6.1552	1.0165	5.5660	1.0199	5.0812	39
22	1.0107	6.8725	1.0135	6.1443	1.0166	5.5572	1.0200	5.0739	38
23	1.0108	6.8589	1.0136	6.1335	1.0166	5.5484	1.0201	5.0666	37
24	1.0108	6.8454	1.0136	6.1227	1.0167	5.5396	1.0201	5.- 593	36
25	1.0109	6.8320	1.0136	6.1120	1.0167	5.5308	1.0202	5.0520	35
26	1.0109	6.8185	1.0137	6.1013	1.0168	5.5221	1.0202	5.0447	34
27	1.0110	6.8052	1.0137	6.0906	1.0169	5.5134	1.0203	5 0375	33
28	1.0110	6.7919	1.0138	6.0800	1.0169	5.5047	1.0204	5.0302	32
29	1.0111	6.7787	1.0138	6.0694	1.0170	5.4960	1.0204	5.0230	31
30	1.0111	6.7655	1.0139	6.0588	1.0170	5.4874	1.0205	5.0158	30
31	1.0111	6.7523	1.0139	6.0483	1.0171	5.4788	1.0205	5.0087	29
32	1.0112	6.7392	1.0140	6.0379	1.0171	5.4702	1.0206	5.0015	28
33	1.0112	6.7262	1.0140	6.0274	1.0172	5.4617	1.0207	4.9944	27
34	1.0113	6.7132	1.0141	6.0170	1.0172	5.4532	1.0207	4.9873	26
35	1.0113	6.7003	1.0141	6.0066	1.0173	5.4447	1.0208	4.9802	25
36	1.0114	6.6874	1.0142	5.9963	1.0174	5.4362	1.0208	4.9732	24
37	1.0114	6.6745	1.0142	5.9860	1.0174	5.4278	1.0209	4.9661	23
38	1.0115	6.6617	1.0143	5.9758	1.0175	5.4194	1.0210	4.9591	22
39	1.0115	6.6490	1.0143	5.9655	1.0175	5.4110	1.0210	4.9521	21
40	1.0115	6.6363	1.0144	5.9554	1.0176	5.4026	1.0211	4.9452	20
41	1.0116	6.6237	1.0144	5.9452	1.0176	5.3943	1.0211	4.9382	19
42	1.0116	6.6111	1.0145	5.9351	1.0177	5.3860	1.0212	4.9313	18
43	1.0117	6.5985	1.0145	5.9250	1.0177	5.3777	1.0213	4.9243	17
44	1.0117	6.5860	1.0146	5.9150	1.0178	5.3695	1.0213	4.9175	16
45	1.0118	6.5736	1.0146	5.9049	1.0179	5.3612	1.0214	4.9106	15
46	1.0118	6.5612	1.0147	5.8950	1.0179	5.3530	1.0215	4.9037	14
47	1.0119	6.5488	1.0147	5.8850	1.0180	5 3449	1.0215	4.8969	13
48	1.0119	6.5365	1.0148	5.8751	1.0180	5.3367	1.0216	4.8901	12
49	1.0119	6.5243	1.0148	5.8652	1.0181	5.3286	1.0216	4.8833	11
50	1.0120	6.5121	1.0149	5.8554	1.0181	5.3205	1.0217	4.8765	10
51	1.0120	6.4999	1.0150	5.8456	1.0182	5.3124	1.0218	4.8697	9
52	1.0121	6.4878	1.0150	5.8358	1.0182	5.3044	1.0218	4.8630	8
53	1.0121	6.4757	1.0151	5.8261	1.0183	5.2963	1.0219	4.8563	7
54	1.0122	6.4637	1.0151	5.8163	1.0184	5.2883	1.0220	4.8496	6
55	1.0122	6.4517	1.0152	5.8067	1.0184	5.2803	1.0220	4.8429	5
56	1.0123	6.4398	1.0152	5.7970	1.0185	5.2724	1.0221	4.8362	4
57	1.0123	6.4279	1.0153	5.7874	1.0185	5.2645	1.0221	4.8296	3
58	1.0124	6.4160	1.0153	5.7778	1.0186	5.2566	1.0222	4.8229	2
59	1.0124	6.4042	1.0154	5.7683	1.0186	5.2487	1.0223	4.8163	1
60	1.0125	6.3924	1.0154	5.7588	1.0187	5.2408	1.0223	4.8097	0
′	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	′
	81°		80°		79°		78°		

12°		13°		14°		15°		
Sec.	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	′
1.0223	4.8097	1.0263	4.4454	1.0306	4.1336	1.0353	3.8637	60
1.0224	4.8032	1.0264	4.4398	1.0307	4.1287	1.0353	3.8595	59
1.0225	4.7966	1.0264	4.4342	1.0308	4.1239	1.0354	3.8553	58
1.0225	4.7901	1.0265	4.4287	1.0308	4.1191	1.0355	3.8512	57
1.0226	4.7835	1.0266	4.4231	1.0309	4.1144	1.0356	3.8470	56
1.0226	4.7770	1.0266	4.4176	1.0310	4.1096	1.0357	3.8428	55
1.0227	4.7706	1.0267	4.4121	1.0311	4.1048	1.0358	3.8387	54
1.0228	4.7641	1.0268	4.4065	1.0311	4.1001	1.0358	3.8346	53
1.0228	4.7576	1.0268	4.4011	1.0312	4.0953	1.0359	3.8304	52
1.0229	4.7512	1.0269	4.3956	1.0313	4.0906	1.0360	3.8263	51
1.0230	4.7448	1.0270	4.3910	1.0314	4.0859	1.0361	3.8222	50
1.0230	4.7384	1.0271	4.3847	1.0314	4.0812	1.0362	3.8181	49
1.0231	4.7320	1.0271	4.3792	1.0315	4.0765	1.0362	3.8140	48
1.0232	4.7257	1.0272	4.3738	1.0316	4.0718	1.0363	3.8100	47
1.0232	4.7193	1.0273	4.3684	1.0317	4.0672	1.0364	3.8059	46
1.0233	4.7130	1.0273	4.3630	1.0317	4.0625	1.0365	3.8018	45
1.0234	4.7067	1.0274	4.3576	1.0318	4.0579	1.0366	3.7978	44
1.0234	4.7004	1.0275	4.3522	1.0319	4.0532	1.0367	3.7937	43
1.0235	4.6942	1.0276	4.3469	1.0320	4.0486	1.0367	3.7897	42
1.0235	4.6879	1.0276	4.3415	1.0320	4.0440	1.0368	3.7857	41
1.0236	4.6817	1.0277	4.3362	1.0321	4.0394	1.0369	3.7816	40
1.0237	4.6754	1.0278	4.3309	1.0322	4.0348	1.0370	3.7776	39
1.0237	4.6692	1.0278	4.3256	1.0323	4.0302	1.0371	3.7736	38
1.0238	4.6631	1.0279	4.3203	1.0323	4.0256	1.0371	3.7697	37
1.0239	4.6569	1.0280	4.3150	1.0324	4.0211	1.0372	3.7657	36
1.0239	4.6507	1.0280	4.3098	1.0325	4.0165	1.0373	3.7617	35
1.0240	4.6446	1.0281	4.3045	1.0326	4.0120	1.0374	3.7577	34
1.0241	4.6385	1.0282	4.2993	1.0327	4.0074	1.0375	3.7538	33
1.0241	4.6324	1.0283	4.2941	1.0327	4.0029	1.0376	3.7498	32
1.0242	4.6263	1.0283	4.2888	1.0328	3.9984	1.0376	3.7459	31
1.0243	4.6202	1.0284	4.2836	1.0329	3.9939	1.0377	3.7420	30
1.0243	4.6142	1.0285	4.2785	1.0330	3.9894	1.0378	3.7380	29
1.0244	4.6081	1.0285	4.2733	1.0330	3.9850	1.0379	3.7341	28
1.0245	4.6021	1.0286	4.2681	1.0331	3.9805	1.0380	3.7302	27
1.0245	4.5961	1.0287	4.2630	1.0332	3.9760	1.0381	3.7263	26
1.0246	4.5901	1.0288	4.2579	1.0333	3.9716	1.0382	3.7224	25
1.0247	4.5841	1.0288	4.2527	1.0334	3.9672	1.0382	3.7186	24
1.0247	4.5782	1.0289	4.2476	1.0334	3.9627	1.0383	3.7147	23
1.0248	4.5722	1.0290	4.2425	1.0335	3.9583	1.0384	3.7108	22
1.0249	4.5663	1.0291	4.2375	1.0336	3.9539	1.0385	3.7070	21
1.0249	4.5604	1.0291	4.2324	1.0337	3.9495	1.0386	3.7031	20
1.0250	4.5545	1.0292	4.2273	1.0338	3.9451	1.0387	3.6993	19
1.0251	4.5486	1.0293	4.2223	1.0338	3.9408	1.0387	3.6955	18
1.0251	4.5428	1.0293	4.2173	1.0339	3.9364	1.0388	3.6917	17
1.0252	4.5369	1.0294	4.2122	1.0340	3.9320	1.0389	3.6878	16
1.0253	4.5311	1.0295	4.2072	1.0341	3.9277	1.0390	3.6840	15
1.0253	4.5253	1.0296	4.2022	1.0341	3.9234	1.0391	3.6802	14
1.0254	4.5195	1.0296	4.1972	1.0342	3.9199	1.0392	3.6765	13
1.0255	4.5137	1.0297	4.1923	1.0343	3.9147	1.0393	3.6727	12
1.0255	4.5079	1.0298	4.1873	1.0344	3.9104	1.0393	3.6689	11
1.0256	4.5021	1.0299	4.1824	1.0345	3.9061	1.0394	3.6651	10
1.0257	4.4964	1.0299	4.1774	1.0345	3.9018	1.0395	3.6614	9
1.0257	4.4907	1.0300	4.1725	1.0346	3.8976	1.0396	3.6576	8
1.0258	4.4850	1.0301	4.1676	1.0347	3.8933	1.0397	3.6539	7
1.0259	4.4793	1.0302	4.1627	1.0348	3.8990	1.0398	3.6502	6
1.0260	4.4736	1.0302	4.1578	1.0349	3.8848	1.0399	3.6464	5
1.0260	4.4679	1.0303	4.1529	1.0349	3.8805	1.0399	3.6427	4
1.0261	4.4623	1.0304	4.1481	1.0350	3.8763	1.0400	3.6390	3
1.0262	4.4566	1.0305	4.1432	1.0351	3.8721	1.0401	3.6353	2
1.0262	4.4510	1.0305	4.1384	1.0352	3.8679	1.0402	3.6316	1
1.0263	4.4454	1.0306	4.1336	1.0353	3.8637	1.0403	3.6279	0
Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	′
77°		76°		75°		74°		

′	16° Sec.	16° Co-sec.	17° Sec.	17° Co-sec.	18° Sec.	18° Co-sec.	19° Sec.	19° Co-sec.	′
0	1.0403	3.6279	1.0457	3.4203	1.0515	3.2361	1.0576	3.0715	60
1	1.0404	3.6243	1.0458	3.4170	1.0516	3.2332	1.0577	3.0690	59
2	1.0405	3.6206	1.0459	3.4138	1.0517	3.2303	1.0578	3.0664	58
3	1.0406	3.6169	1.0460	3.4106	1.0518	3.2274	1.0579	3.0638	57
4	1.0406	3.6133	1.0461	3.4073	1.0519	3.2245	1.0580	3.0612	56
5	1.0407	5.6096	1.0461	3.4041	1.0520	3.2216	1.0581	3.0586	55
6	1.0408	3.6060	1.0462	3.4009	1.0521	3.2188	1.0582	3.0561	54
7	1.0409	3.6024	1.0463	3.3977	1.0522	3.2159	1.0584	3.0535	53
8	1.0410	3.5987	1.0464	3.3945	1.0523	3.2131	1.0585	3.0509	52
9	1.0411	3.5951	1.0465	3.3913	1.0524	3.2102	1.0586	3.0484	51
10	1.0412	3.5915	1.0466	3.3881	1.0525	3.2074	1.0587	3.0458	50
11	1.0413	3.5879	1.0467	3.3849	1.0526	3.2045	1.0588	3.0433	49
12	1.0413	3.5843	1.0468	3.3817	1.0527	3.2017	1.0589	3.0407	48
13	1.0414	3.5807	1.0469	3.3785	1.0528	3.1989	1.0590	3.0382	47
14	1.0415	3.5772	1.0470	3.3754	1.0529	3.1960	1.0591	3.0357	46
15	1.0416	3.5736	1.0471	3.3722	1.0530	3.1932	1.0592	3.0331	45
16	1.0417	3.5700	1.0472	3.3690	1.0531	3.1904	1.0593	3.0306	44
17	1.0418	3.5665	1.0473	3.3659	1.0532	3.1876	1.0594	3.0281	43
18	1.0419	3.5629	1.0474	3.3627	1.0533	3.1848	1.0595	3.0256	42
19	1.0420	3.5594	1.0475	3.3596	1.0534	3.1820	1.0596	3.0231	41
20	1.0420	3.5559	1.0476	3.3565	1.0535	3.1792	1.0598	3.0206	40
21	1.0421	3.5523	1.0477	3.3534	1.0536	3.1764	1.0599	3.0181	39
22	1.0422	3.5488	1.0478	3.3502	1.0537	3.1736	1.0600	3.0156	38
23	1.0423	3.5453	1.0478	3.3471	1.0538	3.1708	1.0601	3.0131	37
24	1.0424	3.5418	1.0479	3.3440	1.0539	3.1681	1.0602	3.0106	36
25	1.0425	3.5383	1.0480	3.3409	1.0540	3.1653	1.0603	3.0081	35
26	1.0426	3.5348	1.0481	3.3378	1.0541	3.1625	1.0604	3.0056	34
27	1.0427	3.5313	1.0482	3.3347	1.0542	3.1598	1.0605	3.0031	33
28	1.0428	3.5279	1.0483	3.3316	1.0543	3.1570	1.0606	3.0007	32
29	1.0428	3.5244	1.0484	3.3286	1.0544	3.1543	1.0607	2.9982	31
30	1.0429	3.5209	1.0485	3.3255	1.0545	3.1515	1.0608	2.9957	30
31	1.0430	3.5175	1.0486	3.3224	1.0546	3.1488	1.0609	2.9933	29
32	1.0431	3.5140	1.0487	3.3194	1.0547	3.1461	1.0611	2.9908	28
33	1.0432	3.5106	1.0488	3.3163	1.0548	3.1433	1.0612	2.9884	27
34	1.0433	3.5072	1.0489	3.3133	1.0549	3.1406	1.0613	2.9859	26
35	1.0434	3.5037	1.0490	3.3102	1.0550	3.1379	1.0614	2.9835	25
36	1.0435	3.5003	1.0491	3.3072	1.0551	3.1352	1.0615	2.9810	24
37	1.0436	3.4969	1.0492	3.3042	1.0552	3.1325	1.0616	2.9786	23
38	1.0437	3.4935	1.0493	3.3011	1.0553	3.1298	1.0617	2.9762	22
39	1.0438	3.4901	1.0494	3.2981	1.0554	3.1271	1.0618	2.9738	21
40	1.0438	3.4867	1.0495	3.2951	1.0555	3.1244	1.0619	2.9713	20
41	1.0439	3.4833	1.0496	3.2921	1.0556	3.1217	1.0620	2.9689	19
42	1.0440	3.4799	1.0497	3.2891	1.0557	3.1190	1.0622	2.9665	18
43	1.0441	3.4766	1.0498	3.2861	1.0558	3.1163	1.0623	2.9641	17
44	1.0442	3.4732	1.0499	3.2831	1.0559	3.1137	1.0624	2.9617	16
45	1.0443	3.4698	1.0500	3.2801	1.0560	3.1110	1.0625	2.9593	15
46	1.0444	3.4665	1.0501	3.2772	1.0561	3.1083	1.0626	2.9569	14
47	1.0445	3.4632	1.0502	3.2742	1.0562	3.1057	1.0627	2.9545	13
48	1.0446	3.4598	1.0503	3.2712	1.0563	3.1030	1.0628	2.9521	12
49	1.0447	3.4565	1.0504	3.2683	1.0565	3.1004	1.0629	2.9497	11
50	1.0448	3.4532	1.0505	3.2653	1.0566	3.0977	1.0630	2.9474	10
51	1.0448	3.4498	1.0506	3.2624	1.0567	3.0951	1.0632	2.9450	9
52	1.0449	3.4465	1.0507	3.2594	1.0568	3.0925	1.0633	2.9426	8
53	1.0450	3.4432	1.0508	3.2565	1.0569	3.0898	1.0634	2.9402	7
54	1.0451	3.4399	1.0509	3.2535	1.0570	3.0872	1.0635	2.9379	6
55	1.0452	3.4366	1.0510	3.2506	1.0571	3.0846	1.0636	2.9355	5
56	1.0453	3.4334	1.0511	3.2477	1.0572	3.0820	1.0637	2.9332	4
57	1.0454	3.4301	1.0512	3.2448	1.0573	3.0793	1.0638	2.9308	3
58	1.0455	3.4268	1.0513	3.2419	1.0574	3.0767	1.0639	2.9285	2
59	1.0456	3.4236	1.0514	3.2390	1.0575	3.0741	1.0641	2.9261	1
60	1.0457	3.4203	1.0515	3.2361	1.0576	3.0715	1.0642	2.9238	0
′	73° Co-sec.	73° Sec.	72° Co-sec.	72° Sec.	71° Co-sec.	71° Sec.	70° Co-sec.	70° Sec.	′

20°		21°		22°		23°		
Sec.	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	′
1.0642	2.9238	1.0711	2.7904	1.0785	2.6695	1.0864	2.5593	60
1.0643	2.9215	1.0713	2.7883	1.0787	2.6675	1.0865	2.5575	59
1.0644	2.9191	1.0714	2.7862	1.0788	2.6656	1.0866	2.5558	58
1.0645	2.9168	1.0715	2.7841	1.0789	2.6637	1.0868	2.5540	57
1.0646	2.9145	1.0716	2.7820	1.0790	2.6618	1.0869	2.5523	56
1.0647	2.9122	1.0717	2.7799	1.0792	2.6599	1.0870	2.5506	55
1.0648	2.9098	1.0719	2.7778	1.0793	2.6580	1.0872	2.5488	54
1.0650	2.9075	1.0720	2.7757	1.0794	2.6561	1.0873	2.5471	53
1.0651	2.9052	1.0721	2.7736	1.0795	2.6542	1.0874	2.5453	52
1.0652	2.9029	1.0722	2.7715	1.0797	2.6523	1.0876	2.5436	51
1.0653	2.9006	1.0723	2.7694	1.0798	2.6504	1.0877	2.5419	50
1.0654	2.8983	1.0725	2.7674	1.0799	2.6485	1.0878	2.5402	49
1.0655	2.8960	1.0726	2.7653	1.0801	2.6466	1.0880	2.5384	48
1.0656	2.8937	1.0727	2.7632	1.0802	2.6447	1.0881	2.5367	47
1.0658	2.8915	1.0728	2.7611	1.0803	2.6428	1.0882	2.5350	46
1.0659	2.8892	1.0729	2.7591	1.0804	2.6410	1.0884	2.5333	45
1.0660	2.8869	1.0731	2.7570	1.0806	2.6391	1.0885	2.5316	44
1.0661	2.8846	1.0732	2.7550	1.0807	2.6372	1.0886	2.5299	43
1.0662	2.8824	1.0733	2.7529	1.0808	2.6353	1.0888	2.5281	42
1.0663	2.8801	1.0734	2.7509	1.0810	2.6335	1.0889	2.5264	41
1.0664	2.8778	1.0736	2.7488	1.0811	2.6316	1.0891	2.5247	40
1.0666	2.8756	1.0737	2.7468	1.0812	2.6297	1.0892	2.5230	39
1.0667	2.8733	1.0738	2.7447	1.0813	2.6279	1.0893	2.5213	38
1.0668	2.8711	1.0739	2.7427	1.0815	2.6260	1.0895	2.5196	37
1.0669	2.8688	1.0740	2.7406	1.0816	2.6242	1.0896	2.5179	36
1.0670	2.8666	1.0742	2.7386	1.0817	2.6223	1.0897	2.5163	35
1.0671	2.8644	1.0743	2.7366	1.0819	2.6205	1.0899	2.5146	34
1.0673	2.8621	1.0744	2.7346	1.0820	2.6186	1.0900	2.5129	33
1.0674	2.8599	1.0745	2.7325	1.0821	2.6168	1.0902	2.5112	32
1.0675	2.8577	1.0747	2.7305	1.0823	2.6150	1.0903	2.5095	31
1.0676	2.8554	1.0748	2.7285	1.0824	2.6131	1.0904	2.5078	30
1.0677	2.8532	1.0749	2.7265	1.0825	2.6113	1.0906	2.5062	29
1.0678	2.8510	1.0750	2.7245	1.0826	2.6095	1.0907	2.5045	28
1.0679	2.8488	1.0751	2.7225	1.0828	2.6076	1.0908	2.5028	27
1.0681	2.8466	1.0753	2.7205	1.0829	2.6058	1.0910	2.5011	26
1.0682	2.8444	1.0754	2.7185	1.0830	2.6040	1.0911	2.4995	25
1.0683	2.8422	1.0755	2.7165	1.0832	2.6022	1.0913	2.4978	24
1.0684	2.8400	1.0756	2.7145	1.0833	2.6003	1.0914	2.4961	23
1.0685	2.8378	1.0758	2.7125	1.0834	2.5985	1.0915	2.4945	22
1.0686	2.8356	1.0759	2.7105	1.0836	2.5967	1.0917	2.4928	21
1.0688	2.8334	1.0760	2.7085	1.0837	2.5949	1.0918	2.4912	20
1.0689	2.8312	1.0761	2.7065	1.0838	2.5931	1.0920	2.4895	19
1.0690	2.8290	1.0763	2.7045	1.0840	2.5913	1.0921	2.4879	18
1.0691	2.8269	1.0764	2.7026	1.0841	2.5895	1.0922	2.4862	17
1.0692	2.8247	1.0765	2.7006	1.0842	2.5877	1.0924	2.4846	16
1.0694	2.8225	1.0766	2.6986	1.0844	2.5859	1.0925	2.4829	15
1.0695	2.8204	1.0768	2.6967	1.0845	2.5841	1.0927	2.4813	14
1.0696	2.8182	1.0769	2.6947	1.0846	2.5823	1.0928	2.4797	13
1.0697	2.8160	1.0770	2.6927	1.0847	2.5805	1.0929	2.4780	12
1.0698	2.8139	1.0771	2.6908	1.0849	2.5787	1.0931	2.4764	11
1.0699	2.8117	1.0773	2.6888	1.0850	2.5770	1.0932	2.4748	10
1.0701	2.8096	1.0774	2.6869	1.0851	2.5752	1.0934	2.4731	9
1.0702	2.8074	1.0775	2.6849	1.0853	2.5734	1.0935	2.4715	8
1.0703	2.8053	1.0776	2.6830	1.0854	2.5716	1.0936	2.4699	7
1.0704	2.8032	1.0778	2.6810	1.0855	2.5699	1.0938	2.4683	6
1.0705	2.8010	1.0779	2.6791	1.0857	2.5681	1.0939	2.4666	5
1.0707	2.7989	1.0780	2.6772	1.0858	2.5663	1.0941	2.4650	4
1.0708	2.7968	1.0781	2.6752	1.0859	2.5646	1.0942	2.4634	3
1.0709	2.7947	1.0783	2.6733	1.0861	2.5628	1.0943	2.4618	2
1.0710	2.7925	1.0784	2.6714	1.0862	2.5610	1.0945	2.4602	1
1.0711	2.7904	1.0785	2.6695	1.0864	2.5593	1.0946	2.4586	0
Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	Co-sec.	Sec.	′
69°		68°		67°		66°		

′	24° Sec.	24° Co-sec.	25° Sec.	25° Co-sec.	26° Sec.	26° Co-sec.	27° Sec.	27° Co-sec.
0	1.0946	2.4586	1.1034	2.3662	1.1126	2.2812	1.1223	2.2027
1	1.0948	2.4570	1.1035	2.3647	1.1127	2.2798	1.1225	2.2014
2	1.0949	2.4554	1.1037	2.3632	1.1129	2.2784	1.1226	2.2002
3	1.0951	2.4538	1.1038	2.3618	1.1131	2.2771	1.1228	2.1989
4	1.0952	2.4522	1.1040	2.3603	1.1132	2.2757	1.1230	2.1977
5	1.0953	2.4506	1.1041	2.3588	1.1134	2.2744	1.1231	2.1964
6	1.0955	2.4490	1.1043	2.3574	1.1135	2.2730	1.1233	2.1952
7	1.0956	2.4474	1.1044	2.3559	1.1137	2.2717	1.1235	2.1939
8	1.0958	2.4458	1.1046	2.3544	1.1139	2.2703	1.1237	2.1927
9	1.0959	2.4442	1.1047	2.3530	1.1140	2.2690	1.1238	2.1914
10	1.0961	2.4426	1.1049	2.3515	1.1142	2.2676	1.1240	2.1902
11	1.0962	2.4411	1.1050	2.3501	1.1143	2.2663	1.1242	2.1889
12	1.0963	2.4395	1.1052	2.3486	1.1145	2.2650	1.1243	2.1877
13	1.0965	2.4379	1.1053	2.3472	1.1147	2.2636	1.1245	2.1865
14	1.0966	2.4363	1.1055	2.3457	1.1148	2 2623	1.1247	2.1852
15	1.0968	2.4347	1.1056	2.3443	1.1150	2.2610	1.1248	2.1840
16	1.0969	2.4332	1.1058	2.3428	1.1151	2.2596	1.1250	2.1828
17	1.0971	2.4316	1.1059	2.3414	1.1153	2.2583	1.1252	2.1815
18	1.0972	2.4300	1.1061	2.3399	1.1155	2.2570	1.1253	2.1803
19	1.0973	2.4285	1.1062	2.3385	1.1156	2.2556	1.1255	2.1791
20	1.0975	2.4269	1.1064	2.3371	1.1158	2.2543	1.1257	2.1778
21	1.0976	2.4254	1.1065	2.3356	1.1159	2.2530	1.1258	2.1766
22	1.0978	2.4238	1.1067	2.3342	1.1161	2.2517	1.1260	2.1754
23	1.0979	2.4222	1.1068	2.3328	1.1163	2.2503	1.1262	2.1742
24	1.0981	2.4207	1.1070	2.3313	1.1164	2.2490	1.1264	2.1730
25	1.0982	2.4191	1.1072	2.3299	1.1166	2.2477	1.1265	2.1717
26	1.0984	2.4176	1.1073	2.3285	1.1167	2.2464	1.1267	2.1705
27	1.0985	2.4160	1.1075	2.3271	1.1169	2.2451	1.1269	2.1693
28	1.0986	2.4145	1.1076	2.3256	1.1171	2.2438	1.1270	2.1681
29	1.0988	2.4130	1.1078	2.3242	1.1172	2.2425	1.1272	2.1669
30	1.0989	2.4114	1.1079	2.3228	1.1174	2.2411	1.1274	2.1657
31	1.0991	2.4099	1.1081	2.3214	1.1176	2.2398	1.1275	2.1645
32	1.0992	2.4083	1.1082	2.3200	1.1177	2.2385	1.1277	2.1633
33	1.0994	2.4068	1.1084	2.3186	1.1179	2.2372	1.1279	2.1620
34	1.0995	2.4053	1.1085	2.3172	1.1180	2.2359	1.1281	2.1608
35	1.0997	2.4037	1.1087	2.3158	1.1182	2.2346	1.1282	2.1596
36	1.0998	2.4022	1.1088	2.3143	1.1184	2.2333	1.1284	2.1584
37	1.1000	2.4007	1.1090	2.3129	1.1185	2.2320	1.1286	2.1572
38	1.1001	2.3992	1.1092	2.3115	1.1187	2.2307	1.1287	2.1560
39	1.1003	2.3976	1.1093	2.3101	1.1189	2.2294	1.1289	2.1548
40	1.1004	2.3961	1.1095	2.3087	1.1190	2.2282	1.1291	2.1536
41	1.1005	2.3946	1.1096	2.3073	1.1192	2.2269	1.1293	2.1525
42	1.1007	2.3931	1.1098	2.3059	1.1193	2.2256	1.1294	2.1513
43	1.1008	2.3916	1.1099	2.3046	1.1195	2.2243	1.1296	2.1501
44	1.1010	2.3901	1.1101	2.3032	1.1197	2.2230	1.1298	2.1489
45	1.1011	2.3886	1.1102	2.3018	1.1198	2.2217	1.1299	2.1477
46	1.1013	2.3871	1.1104	2.3004	1.1200	2.2204	1.1301	2.1465
47	1.1014	2.3856	1.1106	2.2990	1.1202	2.2192	1.1303	2.1453
48	1.1016	2.3841	1.1107	2.2976	1.1203	2.2179	1.1305	2.1441
49	1.1017	2.3826	1.1109	2.2962	1.1205	2.2166	1.1306	2.1430
50	1.1019	2.3811	1.1110	2.2949	1.1207	2.2153	1.1308	2.1418
51	1.1020	2.3796	1.1112	2.2935	1.1208	2.2141	1.1310	2.1406
52	1.1022	2.3781	1.1113	2.2921	1.1210	2.2128	1.1312	2.1394
53	1.1023	2.3766	1.1115	2.2907	1.1212	2.2115	1.1313	2.1382
54	1.1025	2.3751	1.1116	2.2894	1.1213	2.2103	1.1315	2.1371
55	1.1026	2.3736	1.1118	2.2880	1.1215	2.2090	1.1317	2.1359
56	1.1028	2.3721	1.1120	2.2866	1.1217	2.2077	1.1319	2.1347
57	1.1029	2.3706	1.1121	2.2853	1.1218	2.2065	1.1320	2.1335
58	1.1031	2.3691	1.1123	2.2839	1.1220	2.2052	1.1322	2.1324
59	1.1032	2.3677	1.1124	2.2825	1.1222	2.2039	1.1324	2.1312
60	1.1034	2.3662	1.1126	2.2812	1.1223	2.2027	1.1326	2.1300
′	Co-sec. 65°	Sec. 65°	Co-sec. 64°	Sec. 64°	Co-sec. 63°	Sec. 63°	Co-sec. 62°	Sec. 62°

′	28° Sec.	28° Co-sec.	29° Sec.	29° Co-sec.	30° Sec.	30° Co-sec.	31° Sec.	31° Co-sec.	′
0	1.1326	2.1300	1.1433	2.0627	1.1547	2.0000	1.1666	1.9416	60
1	1.1327	2.1289	1.1435	2.0616	1.1549	1.9990	1.1668	1.9407	59
2	1.1329	2.1277	1.1437	2.0605	1.1551	1.9980	1.1670	1.9397	58
3	1.1331	2.1266	1.1439	2.0594	1.1553	1.9970	1.1672	1.9388	57
4	1.1333	2.1254	1.1441	2.0583	1.1555	1.9960	1.1674	1.9378	56
5	1.1334	2.1242	1.1443	2.0573	1.1557	1.9950	1.1676	1.9369	55
6	1.1336	2.1231	1.1445	2.0562	1.1559	1.9940	1.1678	1.9360	54
7	1.1338	2.1219	1.1446	2.0551	1.1561	1.9930	1.1681	1.9350	53
8	1.1340	2.1208	1.1448	2.0540	1.1562	1.9920	1.1683	1.9341	52
9	1.1341	2.1196	1.1450	2.0530	1.1564	1.9910	1.1685	1.9332	51
10	1.1343	2.1185	1.1452	2.0519	1.1566	1.9900	1.1687	1.9322	50
11	1.1345	2.1173	1.1454	2.0508	1.1568	1.9890	1.1689	1.9313	49
12	1.1347	2.1162	1.1456	2.0498	1.1570	1.9880	1.1691	1.9304	48
13	1.1349	2.1150	1.1458	2.0487	1.1572	1.9870	1.1693	1.9295	47
14	1.1350	2.1139	1.1459	2.0476	1.1574	1.9860	1.1695	1.9285	46
15	1.1352	2.1127	1.1461	2.0466	1.1576	1.9850	1.1697	1.9276	45
16	1.1354	2.1116	1.1463	2.0455	1.1578	1.9840	1.1699	1.9267	44
17	1.1356	2.1104	1.1465	2.0444	1.1580	1.9830	1.1701	1.9258	43
18	1.1357	2.1093	1.1467	2.0434	1.1582	1.9820	1.1703	1.9248	42
19	1.1359	2.1082	1.1469	2.0423	1.1584	1.9811	1.1705	1.9239	41
20	1.1361	2.1070	1.1471	2.0413	1.1586	1.9801	1.1707	1.9230	40
21	1.1363	2.1059	1.1473	2.0402	1.1588	1.9791	1.1709	1.9221	39
22	1.1365	2.1048	1.1474	2.0392	1.1590	1.9781	1.1712	1.9212	38
23	1.1366	2.1036	1.1476	2.0381	1.1592	1.9771	1.1714	1.9203	37
24	1.1368	2.1025	1.1478	2.0370	1.1594	1.9761	1.1716	1.9193	36
25	1.1370	2.1014	1.1480	2.0360	1.1596	1.9752	1.1718	1.9184	35
26	1.1372	2.1002	1.1482	2.0349	1.1598	1.9742	1.1720	1.9175	34
27	1.1373	2.0991	1.1484	2.0339	1.1600	1.9732	1.1722	1.9166	33
28	1.1375	2.0980	1.1486	2.0329	1.1602	1.9722	1.1724	1.9157	32
29	1.1377	2.0969	1.1488	2.0318	1.1604	1.9713	1.1726	1.9148	31
30	1.1379	2.0957	1.1489	2.0308	1.1606	1.9703	1.1728	1.9139	30
31	1.1381	2.0946	1.1491	2.0297	1.1608	1.9693	1.1730	1.9130	29
32	1.1382	2.0935	1.1493	2.0287	1.1610	1.9683	1.1732	1.9121	28
33	1.1384	2.0924	1.1495	2.0276	1.1612	1.9674	1.1734	1.9112	27
34	1.1386	2.0912	1.1497	2.0266	1.1614	1.9664	1.1737	1.9102	26
35	1.1388	2.0901	1.1499	2.0256	1.1616	1.9654	1.1739	1.9093	25
36	1.1390	2.0890	1.1501	2.0245	1.1618	1.9645	1.1741	1.9084	24
37	1.1391	2.0879	1.1503	2.0235	1.1620	1.9635	1.1743	1.9075	23
38	1.1393	2.0868	1.1505	2.0224	1.1622	1.9625	1.1745	1.9066	22
39	1.1395	2.0857	1.1507	2.0214	1.1624	1.9616	1.1747	1.9057	21
40	1.1397	2.0846	1.1508	2.0204	1.1626	1.9606	1.1749	1.9048	20
41	1.1399	2.0835	1.1510	2.0194	1.1628	1.9596	1.1751	1.9039	19
42	1.1401	2.0824	1.1512	2.0183	1.1630	1.9587	1.1753	1.9030	18
43	1.1402	2.0812	1.1514	2.0173	1.1632	1.9577	1.1756	1.9021	17
44	1.1404	2.0801	1.1516	2.0163	1.1634	1.9568	1.1758	1.9013	16
45	1.1406	2.0790	1.1518	2.0152	1.1636	1.9558	1.1760	1.9004	15
46	1.1408	2.0779	1.1520	2.0142	1.1638	1.9549	1.1762	1.8995	14
47	1.1410	2.0768	1.1522	2.0132	1.1640	1.9539	1.1764	1.8986	13
48	1.1411	2.0757	1.1524	2.0122	1.1642	1.9530	1.1766	1.8977	12
49	1.1413	2.0746	1.1526	2.0111	1.1644	1.9520	1.1768	1.8968	11
50	1.1415	2.0735	1.1528	2.0101	1.1646	1.9510	1.1770	1.8959	10
51	1.1417	2.0725	1.1530	2.0091	1.1648	1.9501	1.1772	1.8950	9
52	1.1419	2.0714	1.1531	2.0081	1.1650	1.9491	1.1775	1.8941	8
53	1.1421	2.0703	1.1533	2.0071	1.1652	1.9482	1.1777	1.8932	7
54	1.1422	2.0692	1.1535	2.0061	1.1654	1.9473	1.1779	1.8924	6
55	1.1424	2.0681	1.1537	2.0050	1.1656	1.9463	1.1781	1.8915	5
56	1.1426	2.0670	1.1539	2.0040	1.1658	1.9454	1.1783	1.8906	4
57	1.1428	2.0659	1.1541	2.0030	1.1660	1.9444	1.1785	1.8897	3
58	1.1430	2.0648	1.1543	2.0020	1.1662	1.9435	1.1787	1.8888	2
59	1.1432	2.0637	1.1545	2.0010	1.1664	1.9425	1.1790	1.8879	1
60	1.1433	2.0627	1.1547	2.0000	1.1666	1.9416	1.1792	1.8871	0
′	61° Co-sec.	61° Sec.	60° Co-sec.	60° Sec.	59° Co-sec.	59° Sec.	58° Co-sec.	58° Sec.	′

′	32° Sec.	32° Co-sec.	33° Sec.	33° Co-sec.	34° Sec.	34° Co-sec.	35° Sec.	35° Co-sec.	′
0	1.1792	1.8871	1.1924	1.8361	1.2062	1.7883	1.2208	1.7434	60
1	1.1794	1.8862	1.1926	1.8352	1.2064	1.7875	1.2210	1.7427	59
2	1.1796	1.8853	1.1928	1.8344	1.2067	1.7867	1.2213	1.7420	58
3	1.1798	1.8844	1.1930	1.8336	1.2069	1.7860	1.2215	1.7413	57
4	1.1800	1.8836	1.1933	1.8328	1.2072	1.7852	1.2218	1.7405	56
5	1.1802	1.8827	1.1935	1.8320	1.2074	1.7844	1.2220	1.7398	55
6	1.1805	1.8818	1.1937	1.8311	1.2076	1.7837	1.2223	1.7391	54
7	1.1807	1.8809	1.1939	1.8303	1.2079	1.7829	1.2225	1.7384	53
8	1.1809	1.8801	1.1942	1.8295	1.2081	1.7821	1.2228	1.7377	52
9	1.1811	1.8792	1.1944	1.8287	1.2083	1.7814	1.2230	1.7369	51
10	1.1813	1.8783	1.1946	1.8279	1.2086	1.7806	1.2233	1.7362	50
11	1.1815	1 8785	1.1948	1.8271	1.2088	1.7798	1.2235	1.7355	49
12	1.1818	1.8766	1.1951	1.8263	1.2091	1.7791	1.2238	1.7348	48
13	1.1820	1.8757	1.1953	1.8255	1.2093	1.7783	1.2240	1.7341	47
14	1.1822	1.8749	1.1955	1.8246	1.2095	1.7776	1.2243	1.7334	46
15	1.1824	1.8740	1.1958	1.8238	1.2098	1.7768	1.2245	1.7327	45
16	1.1826	1.8731	1.1960	1.8230	1.2100	1.7760	1.2248	1.7319	44
17	1.1828	1.8723	1.1962	1.8222	1.2103	1.7753	1.2250	1.7312	43
18	1.1831	1.8714	1.1964	1.8214	1.2105	1.7745	1.2253	1.7305	42
19	1.1833	1.8706	1.1967	1.8206	1.2107	1.7738	1.2255	1.7298	41
20	1.1835	1.8697	1.1969	1.8198	1.2110	1.7730	1.2258	1.7291	40
21	1.1837	1.8688	1.1971	1.8190	1.2112	1.7723	1.2260	1.7284	39
22	1.1839	1.8680	1.1974	1.8182	1.2115	1.7715	1.2263	1.7277	38
23	1.1841	1.8671	1.1976	1.8174	1.2117	1.7708	1.2265	1.7270	37
24	1.1844	1.8663	1.1978	1.8166	1.2119	1.7700	1.2268	1.7263	36
25	1.1846	1.8654	1.1980	1.8158	1.2122	1.7693	1.2270	1.7256	35
26	1.1848	1.8646	1.1983	1.8150	1.2124	1.7685	1.2273	1.7249	34
27	1.1850	1.8637	1.1985	1.8142	1.2127	1.7678	1.2276	1.7242	33
28	1.1852	1.8629	1.1987	1.8134	1.2129	1.7670	1.2278	1.7234	32
29	1.1855	1.8620	1.1990	1.8126	1.2132	1.7663	1.2281	1.7227	31
30	1.1857	1.8611	1.1992	1.8118	1.2134	1.7655	1.2283	1.7220	30
31	1.1859	1.8603	1.1994	1.8110	1.2136	1.7648	1.2286	1.7213	29
32	1.1861	1.8595	1.1997	1.8102	1.2139	1.7640	1.2288	1.7206	28
33	1.1863	1.8586	1.1999	1.8094	1.2141	1.7633	1.2291	1.7199	27
34	1.1866	1.8578	1.2001	1.8086	1.2144	1.7625	1.2293	1.7192	26
35	1.1868	1.8569	1.2004	1.8078	1.2146	1.7618	1.2296	1.7185	25
36	1.1870	1.8561	1.2006	1.8070	1.2149	1.7610	1.2298	1.7178	24
37	1.1872	1.8552	1.2008	1.8062	1.2151	1.7603	1.2301	1.7171	23
38	1.1874	1.8544	1.2010	1.8054	1.2153	1.7596	1.2304	1.7164	22
39	1.1877	1.8535	1.2013	1.8047	1.2156	1.7588	1.2306	1.7157	21
40	1.1879	1.8527	1.2015	1.8039	1.2158	1.7581	1.2309	1.7151	20
41	1.1881	1.8519	1.2017	1.8031	1.2161	1.7573	1.2311	1.7144	19
42	1.1883	1.8510	1.2020	1.8023	1.2163	1.7566	1.2314	1.7137	18
43	1.1886	1.8502	1.2022	1.8015	1.2166	1.7559	1.2316	1.7130	17
44	1.1888	1.8493	1.2024	1.8007	1.2168	1.7551	1.2319	1.7123	16
45	1.1890	1.8485	1.2027	1.7999	1.2171	1.7544	1.2322	1.7116	15
46	1.1892	1.8477	1.2029	1.7992	1.2173	1.7537	1.2324	1.7109	14
47	1.1894	1.8468	1.2031	1.7984	1.2175	1.7529	1.2327	1.7102	13
48	1.1897	1.8460	1.2034	1.7976	1.2178	1.7522	1.2329	1.7095	12
49	1.1899	1.8452	1.2036	1.7968	1.2180	1.7514	1.2332	1.7088	11
50	1.1901	1.8443	1.2039	1.7960	1.2183	1.7507	1.2335	1.7081	10
51	1.1903	1.8435	1.2041	1.7953	1.2185	1.7500	1.2337	1.7075	9
52	1.1906	1.8427	1.2043	1.7945	1.2188	1.7493	1.2340	1.7068	8
53	1.1908	1.8418	1.2046	1.7937	1.2190	1.7485	1.2342	1.7061	7
54	1.1910	1.8410	1.2048	1.7929	1.2193	1.7478	1.2345	1.7054	6
55	1.1912	1.8402	1.2050	1.7921	1.2195	1.7471	1.2348	1.7047	5
56	1.1915	1.8394	1.2053	1.7914	1.2198	1.7463	1.2350	1.7040	4
57	1.1917	1.8385	1.2055	1.7906	1.2200	1.7456	1.2353	1.7033	3
58	1.1919	1.8377	1.2057	1.7898	1.2203	1.7449	1.2355	1.7027	2
59	1.1921	1.8369	1.2060	1.7891	1.2205	1.7442	1.2358	1.7020	1
60	1.1922	1.8361	1.2062	1.7883	1.2208	1.7434	1.2361	1.7013	0
′	57° Co-sec.	57° Sec.	56° Co-sec.	56° Sec.	55° Co-sec.	55° Sec.	54° Co-sec.	54° Sec.	′

′	36° Sec.	36° Co-sec.	37° Sec.	37° Co-sec.	38° Sec.	38° Co-sec.	39° Sec.	39° Co-sec.	′
0	1.2361	1.7013	1.2521	1.6616	1.2690	1.6243	1.2867	1.5890	60
1	1.2363	1.7006	1.2524	1.6610	1.2693	1.6237	1.2871	1.5884	59
2	1.2366	1.6999	1.2527	1.6603	1.2696	1.6231	1.2874	1.5879	58
3	1.2368	1.6993	1.2530	1.6597	1.2699	1.6224	1.2877	1.5873	57
4	1.2371	1.6986	1.2532	1.6591	1.2702	1.6218	1.2880	1.5867	56
5	1.2374	1.6979	1.2535	1.6584	1.2705	1.6212	1.2883	1.5862	55
6	1.2376	1.6972	1.2538	1.6578	1.2707	1.6206	1.2886	1.5856	54
7	1.2379	1.6965	1.2541	1.6572	1.2710	1.6200	1.2889	1.5850	53
8	1.2382	1.6959	1.2543	1.6565	1.2713	1.6194	1.2892	1.5845	52
9	1.2384	1.6952	1.2546	1.6559	1.2716	1.6188	1.2895	1.5839	51
10	1.2387	1.6945	1.2549	1.6552	1.2719	1.6182	1.2898	1.5833	50
11	1.2389	1.6938	1.2552	1.6546	1.2722	1.6176	1.2901	1.5828	49
12	1.2392	1.6932	1.2554	1.6540	1.2725	1.6170	1.2904	1.5822	48
13	1.2395	1.6925	1.2557	1.6533	1.2728	1.6164	1.2907	1.5816	47
14	1.2397	1.6918	1.2560	1.6527	1.2731	1.6159	1.2910	1.5811	46
15	1.2400	1.6912	1.2563	1.6521	1.2734	1.6153	1.2913	1.5805	45
16	1.2403	1.6905	1.2565	1.6514	1.2737	1.6147	1.2916	1.5799	44
17	1.2405	1.6898	1.2568	1.6508	1.2739	1.6141	1.2919	1.5794	43
18	1.2408	1.6891	1.2571	1.6502	1.2742	1.6135	1.2922	1.5788	42
19	1.2411	1.6885	1.2574	1.6496	1.2745	1.6129	1.2926	1.5783	41
20	1.2413	1.6878	1.2577	1.6489	1.2748	1.6123	1.2929	1.5777	40
21	1.2416	1.6871	1.2579	1.6483	1.2751	1.6117	1.2932	1.5771	39
22	1.2419	1.6865	1.2582	1.6477	1.2754	1.6111	1.2935	1.5766	38
23	1.2421	1.6858	1.2585	1.6470	1.2757	1.6105	1.2938	1.5760	37
24	1.2424	1.6851	1.2588	1.6464	1.2760	1.6099	1.2941	1.5755	36
25	1.2427	1.6845	1.2591	1.6458	1.2763	1.6093	1.2944	1.5749	35
26	1.2429	1.6838	1.2593	1.6452	1.2766	1.6087	1.2947	1.5743	34
27	1.2432	1.6831	1.2596	1.6445	1.2769	1.6081	1.2950	1.5738	33
28	1.2435	1.6825	1.2599	1.6439	1.2772	1.6077	1.2953	1.5732	32
29	1.2437	1.6818	1.2602	1.6433	1.2775	1.6070	1.2956	1.5727	31
30	1.2440	1.6812	1.2605	1.6427	1.2778	1.6064	1.2960	1.5721	30
31	1.2443	1.6805	1.2607	1.6420	1.2781	1.6058	1.2963	1.5716	29
32	1.2445	1.6798	1.2610	1.6414	1.2784	1.6052	1.2966	1.5710	28
33	1.2448	1.6792	1.2613	1.6408	1.2787	1.6046	1.2969	1.5705	27
34	1.2451	1.6785	1.2616	1.6402	1.2790	1.6040	1.2972	1.5699	26
35	1.2453	1.6779	1.2619	1.6396	1.2793	1.6034	1.2975	1.5694	25
36	1.2456	1.6772	1.2622	1.6389	1.2795	1.6029	1.2978	1.5688	24
37	1.2459	1.6766	1.2624	1.6383	1.2798	1.6023	1.2981	1.5683	23
38	1.2461	1.6759	1.2627	1.6377	1.2801	1.6017	1.2985	1.5677	22
39	1.2464	1.6752	1.2630	1.6371	1.2804	1.6011	1.2988	1.5672	21
40	1.2467	1.6746	1.2633	1.6365	1.2807	1.6005	1.2991	1.5666	20
41	1.2470	1.6739	1.2636	1.6359	1.2810	1.6000	1.2994	1.5661	19
42	1.2472	1.6733	1.2639	1.6352	1.2813	1.5994	1.2997	1.5655	18
43	1.2475	1.6726	1.2641	1.6346	1.2816	1.5988	1.3000	1.5650	17
44	1.2478	1.6720	1.2644	1.6340	1.2819	1.5982	1.3003	1.5644	16
45	1.2480	1.6713	1.2647	1.6334	1.2822	1.5976	1.3006	1.5639	15
46	1.2483	1.6707	1.2650	1.6328	1.2825	1.5971	1.3010	1.5633	14
47	1.2486	1.6700	1.2653	1.6322	1.2828	1.5965	1.3013	1.5628	13
48	1.2488	1.6694	1.2656	1.6316	1.2831	1.5959	1.3016	1.5622	12
49	1.2490	1.6687	1.2659	1.6309	1.2834	1.5953	1.3019	1.5617	11
50	1.2494	1.6681	1.2661	1.6303	1.2837	1.5947	1.3022	1.5611	10
51	1.2497	1.6674	1.2664	1.6297	1.2840	1.5942	1.3025	1.5606	9
52	1.2499	1.6668	1.2667	1.6291	1.2843	1.5936	1.3029	1.5600	8
53	1.2502	1.6661	1.2670	1.6285	1.2846	1.5930	1.3032	1.5595	7
54	1.2505	1.6655	1.2673	1.6279	1.2849	1.5924	1.3035	1.5590	6
55	1.2508	1.6648	1.2676	1.6273	1.2852	1.5919	1.3038	1.5584	5
56	1.2510	1.6642	1.2679	1.6267	1.2855	1.5913	1.3041	1.5579	4
57	1.2513	1.6636	1.2681	1.6261	1.2858	1.5907	1.3044	1.5573	3
58	1.2516	1.6629	1.2684	1.6255	1.2861	1.5901	1.3048	1.5568	2
59	1.2519	1.6623	1.2687	1.6249	1.2864	1.5896	1.3051	1.5563	1
60	1.2521	1.6616	1.2690	1.6243	1.2867	1.5890	1.3054	1.5557	0
′	Co-sec. 53°	Sec. 53°	Co-sec. 52°	Sec. 52°	Co-sec. 51°	Sec. 51°	Co-sec. 50°	Sec. 50°	′

′	40° Sec.	40° Co-sec.	41° Sec.	41° Co-sec.	42° Sec.	42° Co-sec.	43° Sec.	43° Co-sec.	′
0	1.3054	1.5557	1.3250	1.5242	1.3456	1.4945	1.3673	1.4663	60
1	1.3057	1.5552	1.3253	1.5237	1.3460	1.4940	1.3677	1.4658	59
2	1.3060	1.5546	1.3257	1.5232	1.3463	1.4935	1.3681	1.4654	58
3	1.3064	1.5541	1.3260	1.5227	1.3467	1.4930	1.3684	1.4649	57
4	1.3067	1.5536	1.3263	1.5222	1.3470	1.4925	1.3688	1.4644	56
5	1.3070	1.5530	1.3267	1.5217	1.3474	1.4921	1.3692	1.4640	55
6	1.3073	1.5525	1.3270	1.5212	1.3477	1.4916	1.3695	1.4635	54
7	1.3076	1.5520	1.3274	1.5207	1.3481	1.4911	1.3699	1.4631	53
8	1.3080	1.5514	1.3277	1.5202	1.3485	1.4906	1.3703	1.4626	52
9	1.3083	1.5509	1.3280	1.5197	1.3488	1.4901	1.3707	1.4622	51
10	1.3086	1.5503	1.3284	1.5192	1.3492	1.4897	1.3710	1.4617	50
11	1.3089	1.5498	1.3287	1.5187	1.3495	1.4892	1.3714	1.4613	49
12	1.3092	1.5493	1.3290	1.5182	1.3499	1.4887	1.3718	1.4608	48
13	1.3096	1.5487	1.3294	1.5177	1.3502	1.4882	1.3722	1.4604	47
14	1.3099	1.5482	1.3297	1.5171	1.3506	1.4877	1.3725	1.4599	46
15	1.3102	1.5477	1.3301	1.5166	1.3509	1.4873	1.3729	1.4595	45
16	1.3105	1.5471	1.3304	1.5161	1.3513	1.4868	1.3733	1.4590	44
17	1.3109	1.5466	1.3307	1.5156	1.3517	1.4863	1.3737	1.4586	43
18	1.3112	1.5461	1.3311	1.5151	1.3520	1.4858	1.3740	1.4581	42
19	1.3115	1.5456	1.3314	1.5146	1.3524	1.4854	1.3744	1.4577	41
20	1.3118	1.5450	1.3318	1.5141	1.3527	1.4849	1.3748	1.4572	40
21	1.3121	1.5445	1.3321	1.5136	1.3531	1.4844	1.3752	1.4568	39
22	1.3125	1.5440	1.3324	1.5131	1.3534	1.4839	1.3756	1.4563	38
23	1.3128	1.5434	1.3328	1.5126	1.3538	1.4835	1.3759	1.4559	37
24	1.3131	1.5429	1.3331	1.5121	1.3542	1.4830	1.3763	1.4554	36
25	1.3134	1.5424	1.3335	1.5116	1.3545	1.4825	1.3767	1.4550	35
26	1.3138	1.5419	1.3338	1.5111	1.3549	1.4821	1.3771	1.4545	34
27	1.3141	1.5413	1.3342	1.5106	1.3552	1.4816	1.3774	1.4541	33
28	1.3144	1.5408	1.3345	1.5101	1.3556	1.4811	1.3778	1.4536	32
29	1.3148	1.5403	1.3348	1.5096	1.3560	1.4806	1.3782	1.4532	31
30	1.3151	1.5398	1.3352	1.5092	1.3563	1.4802	1.3786	1.4527	30
31	1.3154	1.5392	1.3355	1.5087	1.3567	1.4797	1.3790	1.4523	29
32	1.3157	1.5387	1.3359	1.5082	1.3571	1.4792	1.3794	1.4518	28
33	1.3161	1.5382	1.3362	1.5077	1.3574	1.4788	1.3797	1.4514	27
34	1.3164	1.5377	1.3366	1.5072	1.3578	1.4783	1.3801	1.4510	26
35	1.3167	1.5371	1.3369	1.5067	1.3581	1.4778	1.3805	1.4505	25
36	1.3170	1.5366	1.3372	1.5062	1.3585	1.4774	1.3809	1.4501	24
37	1.3174	1.5361	1.3376	1.5057	1.3589	1.4769	1.3813	1.4496	23
38	1.3177	1.5356	1.3379	1.5052	1.3592	1.4764	1.3816	1.4492	22
39	1.3180	1.5351	1.3383	1.5047	1.3596	1.4760	1.3820	1.4487	21
40	1.3184	1.5345	1.3386	1.5042	1.3600	1.4755	1.3824	1.4483	20
41	1.3187	1.5340	1.3390	1.5037	1.3603	1.4750	1.3828	1.4479	19
42	1.3190	1.5335	1.3393	1.5032	1.3607	1.4746	1.3832	1.4474	18
43	1.3193	1.5330	1.3397	1.5027	1.3611	1.4741	1.3836	1.4470	17
44	1.3197	1.5325	1.3400	1.5022	1.3614	1.4736	1.3839	1.4465	16
45	1.3200	1.5319	1.3404	1.5018	1.3618	1.4732	1.3843	1.4461	15
46	1.3203	1.5314	1.3407	1.5013	1.3622	1.4727	1.3847	1.4457	14
47	1.3207	1.5309	1.3411	1.5008	1.3625	1.4723	1.3851	1.4452	13
48	1.3210	1.5304	1.3414	1.5003	1.3629	1.4718	1.3855	1.4448	12
49	1.3213	1.5299	1.3418	1.4998	1.3633	1.4713	1.3859	1.4443	11
50	1.3217	1.5294	1.3421	1.4993	1.3636	1.4709	1.3863	1.4439	10
51	1.3220	1.5289	1.3425	1.4988	1.3640	1.4704	1.3867	1.4435	9
52	1.3223	1.5283	1.3428	1.4983	1.3644	1.4699	1.3870	1.4430	8
53	1.3227	1.5278	1.3432	1.4979	1.3647	1.4695	1.3874	1.4426	7
54	1.3230	1.5273	1.3435	1.4974	1.3651	1.4690	1.3878	1.4422	6
55	1.3233	1.5268	1.3439	1.4969	1.3655	1.4686	1.3882	1.4417	5
56	1.3237	1.5263	1.3442	1.4964	1.3658	1.4681	1.3886	1.4413	4
57	1.3240	1.5258	1.3446	1.4959	1.3662	1.4676	1.3890	1.4408	3
58	1.3243	1.5253	1.3449	1.4954	1.3666	1.4672	1.3894	1.4404	2
59	1.3247	1.5248	1.3453	1.4949	1.3669	1.4667	1.3898	1.4400	1
60	1.3250	1.5242	1.3456	1.4945	1.3673	1.4663	1.3902	1.4395	0
′	49° Co-sec.	49° Sec.	48° Co-sec.	48° Sec.	47° Co-sec.	47° Sec.	46° Co-sec.	46° Sec.	′

	44°				44°				44°		
′	Sec.	Co-sec.	′	′	Sec.	Co-sec.	′	′	Sec.	Co-sec.	′
0	1.3902	1.4395	60	21	1.3984	1.4305	39	41	1.4065	1.4221	19
1	1.3905	1.4391	59	22	1.3988	1.4301	38	42	1.4069	1.4217	18
2	1.3909	1.4387	58	23	1.3992	1.4297	37	43	1.4073	1.4212	17
3	1.3913	1.4382	57	24	1.3996	1.4292	36	44	1 4077	1.4208	16
4	1.3917	1.4378	56	25	1.4000	1.4288	35	45	1.4081	1.4204	15
5	1.3921	1.4374	55	26	1.4004	1.4284	34	46	1.4085	1.4200	14
6	1.3925	1.4370	54	27	1.4008	1.4280	33	47	1.4089	1.4196	13
7	1.3929	1.4365	53	28	1.4012	1.4276	32	48	1.4093	1.4192	12
8	1.3933	1.4361	52	29	1.4016	1.4271	31	49	1.4097	1.4188	11
9	1.3937	1.4357	51	30	1.4020	1.4267	30	50	1.4101	1.4183	10
10	1.3941	1.4352	50	31	1.4024	1.4263	29	51	1.4105	1.4179	9
11	1.3945	1.4348	49	32	1.4028	1.4259	28	52	1.4109	1.4175	8
12	1.3949	1.4344	48	33	1.4032	1.4254	27	53	1.4113	1.4171	7
13	1.3953	1.4339	47	34	1.4036	1.4250	26	54	1.4117	1.4167	6
14	1.3957	1.4335	46	35	1.4040	1.4246	25	55	1.4122	1.4163	5
15	1.3960	1.4331	45	36	1.4044	1.4242	24	56	1.4126	1.4159	4
16	1.3964	1.4327	44	37	1.4048	1.4238	23	57	1.4130	1.4154	3
17	1.3968	1.4322	43	38	1.4052	1.4233	22	58	1.4134	1.4150	2
18	1.3972	1.4318	42	39	1.4056	1.4229	21	59	1.4138	1.4146	1
19	1.3976	1.4314	41	40	1.4060	1.4225	20	60	1.4142	1.4142	0
20	1.3980	1.4310	40								
′	Co-sec.	Sec.	′	′	Co-sec.	Sec.	′	′	Co-sec.	Sec.	′
	45°				45°				45°		

TABLE 74

N.	0	1	2	3	4	5	6	7	8	9	Diff.
100	000000	0434	0868	1301	1734	2166	2598	3029	3461	3891	432
101	4321	4751	5181	5609	6038	6466	6894	7321	7748	8174	428
102	8600	9026	9451	9876	*0300	*0724	*1147	*1570	*1993	*2415	424
103	012837	3259	3680	4100	4521	4940	5360	5779	6197	6616	420
104	7033	7451	7868	8284	8700	9116	9532	9947	*0361	*0775	416
105	021189	1603	2016	2428	2841	3252	3664	4075	4486	4896	412
106	5306	5715	6125	6533	6942	7350	7757	8164	8571	8978	408
107	9384	9789	*0195	*0600	*1004	*1408	*1812	*2216	*2619	*3021	404
108	033424	3826	4227	4628	5029	5430	5830	6230	6629	7028	400
109	7426	7825	8223	8620	9017	9414	9811	*0207	*0602	*0998	397

N.	Diff.	1	2	3	4	5	6	7	8	9	Diff.
PROPORTIONAL PARTS	434	43	87	130	174	217	260	304	347	391	434
	433	43	87	130	173	217	260	303	346	390	433
	432	43	86	130	173	216	259	302	346	389	432
	431	43	86	129	172	216	259	302	345	388	431
	430	43	86	129	172	215	258	301	344	387	430
	429	43	86	129	172	215	257	300	343	386	429
	428	43	86	128	171	214	257	300	342	385	428
	427	43	85	128	171	214	256	299	342	384	427
	426	43	85	128	170	213	256	298	341	383	426
	425	43	85	128	170	213	255	298	340	383	425
	424	42	85	127	170	212	254	297	339	382	424
	423	42	85	127	169	212	254	296	338	381	423
	422	42	84	127	169	211	253	295	338	380	422
	421	42	84	126	168	211	253	295	337	379	421
	420	42	84	126	168	210	252	294	336	378	420
	419	42	84	126	168	210	251	293	335	377	419
	418	42	84	125	167	209	251	293	334	376	418
	417	42	83	125	167	209	250	292	334	375	417
	416	42	83	125	166	208	250	291	333	374	416
	415	42	83	125	166	208	249	291	332	374	415
	414	41	83	124	166	207	248	290	331	373	414
	413	41	83	124	165	207	248	289	330	372	413
	412	41	82	124	165	206	247	288	330	371	412
	411	41	82	123	164	206	247	288	329	370	411
	410	41	82	123	164	205	246	287	328	369	410
	409	41	82	123	164	205	245	286	327	368	409
	408	41	82	122	163	204	245	286	326	367	408
	407	41	81	122	163	204	244	285	326	366	407
	406	41	81	122	162	203	244	284	325	365	406
	405	41	81	122	162	203	243	284	324	365	405
	404	40	81	121	162	202	242	283	323	364	404
	403	40	81	121	161	202	242	282	322	363	403
	402	40	80	121	161	201	241	281	322	362	402
	401	40	80	120	160	201	241	281	321	361	401
	400	40	80	120	160	200	240	280	320	360	400
	399	40	80	120	160	200	239	279	319	359	399
	398	40	80	119	159	199	239	279	318	358	398
	397	40	79	119	159	199	238	278	318	357	397
	396	40	79	119	158	198	238	277	317	356	396
	395	40	79	119	158	198	237	277	316	356	395
	394	39	79	118	158	197	236	276	315	355	394
	393	39	79	118	157	197	236	275	314	354	393
	392	39	78	118	157	196	235	274	314	353	392
	391	39	78	117	156	196	235	274	313	352	391
	390	39	78	117	156	195	234	273	312	351	390
	389	39	78	117	156	195	233	272	311	350	389
	388	39	78	116	155	194	233	272	310	349	388
	Diff.	1	2	3	4	5	6	7	8	9	Diff.

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N.	0	1	2	3	4	5	6	7	8	9	Diff.
110	041393	1787	2182	2576	2969	3362	3755	4148	4540	4932	393
111	5323	5714	6105	6495	6885	7275	7664	8053	8442	8830	390
112	9218	9606	9993	*0380	*0766	*1153	*1538	*1924	*2309	*2694	386
113	053078	3463	3846	4230	4613	4996	5378	5760	6142	6524	383
114	6905	7286	7666	8046	8426	8805	9185	9563	9942	*0320	379
115	060698	1075	1452	1829	2206	2582	2958	3333	3709	4083	376
116	4458	4832	5206	5580	5953	6326	6699	7071	7443	7815	373
117	8186	8557	8928	9298	9668	*0038	*0407	*0776	*1145	*1514	370
118	071882	2250	2617	2985	3352	3718	4085	4451	4816	5182	366
119	5547	5912	6276	6640	7004	7368	7731	8094	8457	8819	363
120	079181	9543	9904	*0266	*0626	*0987	*1347	*1707	*2067	*2426	360
121	082785	3144	3503	3861	4219	4576	4934	5291	5647	6004	357
122	6360	6716	7071	7426	7781	8136	8490	8845	9198	9552	355
123	9905	*0258	*0611	*0963	*1315	*1667	*2018	*2370	*2721	*3071	352
124	093422	3772	4122	4471	4820	5169	5518	5866	6215	6562	349

PROPORTIONAL PARTS

N.	Diff.	1	2	3	4	5	6	7	8	9	Diff.
	387	39	77	116	155	194	232	271	310	348	387
	386	39	77	116	154	193	232	270	309	347	386
	385	39	77	116	154	193	231	270	308	347	385
	384	38	77	115	154	192	230	269	307	346	384
	383	38	77	115	153	192	230	268	306	345	383
	382	38	76	115	153	191	229	267	306	344	382
	381	38	76	114	152	191	229	267	305	343	381
	380	38	76	114	152	190	228	266	304	342	380
	379	38	76	114	152	190	227	265	303	341	379
	378	38	76	113	151	189	227	265	302	340	378
	377	38	75	113	151	189	226	264	302	339	377
	376	38	75	113	150	188	226	263	301	338	376
	375	38	75	113	150	188	225	263	300	338	375
	374	37	75	112	150	187	224	262	299	337	374
	373	37	75	112	149	187	224	261	298	336	373
	372	37	74	112	149	186	[illegible]	260	298	335	372
	371	37	74	111	148	186	223	260	297	334	371
	370	37	74	111	148	185	222	259	296	333	370
	369	37	74	111	148	185	221	258	295	332	369
	368	37	74	110	147	184	221	258	294	331	368
	367	37	73	110	147	184	220	257	294	330	367
	366	37	73	110	146	183	220	256	293	329	366
	365	37	73	110	146	183	219	256	292	329	365
	364	36	73	109	146	182	218	255	291	328	364
	363	36	73	109	145	182	218	254	290	327	363
	362	36	72	109	145	181	217	253	290	326	362
	361	36	72	108	144	181	217	253	289	325	361
	360	36	72	108	144	180	216	252	288	324	360
	359	[illegible]	72	108	144	180	215	251	287	323	359
	358	[illegible]	72	107	143	179	215	251	286	322	358
	357	36	71	107	143	179	214	250	286	321	357
	356	36	71	107	142	178	214	249	285	320	356
	355	36	71	107	142	178	213	249	284	320	355
	354	35	71	106	142	177	212	248	283	319	354
	353	35	71	106	141	177	212	247	282	318	353
	352	35	70	106	141	176	211	246	282	317	352
	351	35	70	105	140	176	211	246	281	316	351
	350	35	70	105	140	175	210	245	280	315	350
	349	35	70	105	140	175	[illegible]	244	279	314	349
	348	35	70	104	139	174	209	244	278	313	348
	347	35	69	104	139	174	208	243	278	312	347

	Diff.	1	2	3	4	5	6	7	8	9	Diff.

N.	0	1	2	3	4	5	6	7	8	9	DIFF.
125	096910	7257	7604	7951	8298	8644	8990	9335	9681	*0026	346
126	100371	0715	1059	1403	1747	2091	2434	2777	3119	3462	343
127	3804	4146	4487	4828	5169	5510	5851	6191	6531	6871	[illegible]
128	7210	7549	7888	8227	8565	8903	9241	9579	9916	*0253	338
129	110590	0926	1263	1599	1934	2270	2605	2940	3275	3609	335
130	113943	4277	4611	4944	5278	5611	5943	6276	6608	6940	333
131	7271	7603	7934	8265	8595	8926	9256	9586	9915	*0245	330
132	120574	0903	1231	1560	1888	2216	2544	2871	3198	3525	[illegible]
133	3852	4178	4504	4830	5156	5481	5806	6131	6456	6781	325
134	7105	7429	7753	8076	8399	8722	9045	9368	9690	*0012	323
135	130334	0655	0977	1298	1619	1939	2260	2580	2900	3219	321
136	3539	3858	4177	4496	4814	5133	5451	5769	6086	6403	318
137	6721	7037	7354	7671	7987	8303	8618	8934	9249	9564	316
138	9879	*0194	*0508	*0822	*1136	*1450	*1763	*2076	*2389	*2702	314
139	143015	3327	3639	3951	4263	4574	4885	5196	5507	5818	311

N.	Diff.	1	2	3	4	5	6	7	8	9	Diff.
PROPORTIONAL PARTS	347	35	69	104	139	174	208	243	278	312	347
	346	35	69	104	138	173	208	242	277	311	346
	345	35	69	104	138	173	207	242	276	311	345
	344	34	69	103	138	172	206	241	275	310	344
	343	34	69	103	137	172	206	240	274	309	343
	342	34	68	103	137	171	205	239	274	308	342
	341	34	68	102	136	171	205	239	273	307	341
	340	34	68	102	136	170	204	238	272	306	340
	339	34	68	102	136	170	203	237	271	305	339
	338	34	68	101	135	169	203	237	270	304	338
	337	34	67	101	135	169	202	236	270	303	337
	336	34	67	101	134	168	202	235	269	302	336
	335	34	67	101	134	168	201	235	268	302	[illegible]
	334	33	67	100	134	167	200	234	267	301	[illegible]
	333	33	67	100	133	167	200	233	266	300	[illegible]
	332	33	66	100	133	166	199	232	266	299	[illegible]
	331	33	66	99	132	166	199	232	265	298	331
	330	33	66	99	132	165	198	231	264	297	330
	329	33	66	99	132	165	197	230	263	296	329
	328	33	66	98	131	164	197	230	262	295	328
	327	33	65	98	131	164	196	229	262	294	327
	326	33	65	98	130	163	196	228	261	293	326
	325	33	65	98	130	163	195	228	260	293	325
	324	32	65	97	130	162	194	227	259	292	324
	323	32	65	97	129	162	194	226	258	291	323
	322	32	64	97	129	161	193	225	258	290	322
	321	32	64	96	128	161	193	225	257	289	321
	320	32	64	96	128	160	192	224	256	288	320
	[illegible]	32	64	96	128	160	191	223	255	287	319
	318	32	64	95	127	159	191	223	254	286	318
	317	32	63	95	127	159	190	222	254	285	317
	316	32	63	95	126	158	190	221	253	284	316
	315	32	63	95	126	158	189	221	252	284	315
	314	31	63	94	126	157	188	220	251	283	314
	313	31	63	94	125	157	188	219	250	282	313
	312	31	62	94	125	156	187	218	250	281	312
	311	31	62	93	124	156	187	218	249	280	311
	310	31	62	93	124	155	186	217	248	279	310
	309	31	62	93	124	155	185	216	247	278	309
	308	31	62	92	123	154	185	216	246	277	308
	307	31	61	92	123	154	184	215	246	276	307
	Diff.	1	2	3	4	5	6	7	8	9	Diff.

N.	0	1	2	3	4	5	6	7	8	9	Diff.
140	146128	6438	6748	7058	7367	7676	7985	8294	8603	8911	309
141	9219	9527	9835	*0142	*0449	*0756	*1063	*1370	*1676	*1982	307
142	152288	2594	2900	3205	3510	3815	4120	4424	4728	5032	305
143	5336	5640	5943	6246	6549	6852	7154	7457	7759	8061	303
144	8362	8664	8965	9266	9567	9868	*0168	*0469	*0769	*1068	301
145	161368	1667	1967	2266	2564	2863	3161	3460	3758	4055	299
146	4353	4650	4947	5244	5541	5838	6134	6430	6726	7022	297
147	7317	7613	7908	8203	8497	8792	9086	9380	9674	9968	295
148	170262	0555	0848	1141	1434	1726	2019	2311	2603	2895	293
149	3186	3478	3769	4060	4351	4641	4932	5222	5512	5802	291
150	176091	6381	6670	6959	7248	7536	7825	8113	8401	8689	289
151	8977	9264	9552	9839	*0126	*0413	*0699	*0986	*1272	*1558	287
152	181844	2129	2415	2700	2985	3270	3555	3839	4123	4407	285
153	4691	4975	5259	5542	5825	6108	6391	6674	6956	7239	283
154	7521	7803	8084	8366	8647	8928	9209	9490	9771	*0051	281
155	190332	0612	0892	1171	1451	1730	2010	2289	2567	2846	279
156	3125	3403	3681	3959	4237	4514	4792	5069	5346	5623	278
157	5900	6176	6453	6729	7005	7281	7556	7832	8107	8382	276
158	8657	8932	9206	9481	9755	*0029	*0303	*0577	*0850	*1124	274
159	201397	1670	1943	2216	2488	2761	3033	3305	3577	3848	272

PROPORTIONAL PARTS

N.	Diff.	1	2	3	4	5	6	7	8	9	Diff.
	306	31	61	92	122	153	184	214	245	275	306
	305	31	61	92	122	153	183	214	244	275	305
	304	30	61	91	122	152	182	213	243	274	304
	303	30	61	91	121	152	182	212	242	273	303
	302	30	60	91	121	151	181	211	242	272	302
	301	30	60	90	120	151	181	211	241	271	301
	300	30	60	90	120	150	180	210	240	270	300
	299	30	60	90	120	150	179	209	239	269	299
	298	30	60	89	119	149	179	209	238	268	298
	297	30	59	89	119	149	178	208	238	267	297
	296	30	59	89	118	148	178	207	237	266	296
	295	30	59	89	118	148	177	207	236	266	295
	294	29	59	88	118	147	176	206	235	265	294
	293	29	59	88	117	147	176	205	234	264	293
	292	29	58	88	117	146	175	204	234	263	292
	291	29	58	87	116	146	175	204	233	262	291
	290	29	58	87	116	145	174	203	232	261	290
	289	29	58	87	116	145	173	202	231	260	289
	288	29	58	86	115	144	173	202	230	259	288
	287	29	57	86	115	144	172	201	230	258	287
	286	29	57	86	114	143	172	200	229	257	286
	285	29	57	86	114	143	171	200	228	257	285
	284	28	57	85	114	142	170	199	227	256	284
	283	28	57	85	113	142	170	198	226	255	283
	282	28	56	85	113	141	169	197	226	254	282
	281	28	56	84	112	141	169	197	225	253	281
	280	28	56	84	112	140	168	196	224	252	280
	279	28	56	84	112	140	167	195	223	251	279
	278	28	56	83	111	139	167	195	222	250	278
	277	28	55	83	111	139	166	194	222	249	277
	276	28	55	83	110	138	166	193	221	248	276
	275	28	55	83	110	138	165	193	220	248	275
	274	27	55	82	110	137	164	192	219	247	274
	273	27	55	82	109	137	164	191	218	246	273
	272	27	54	82	109	136	163	190	218	245	272
	271	27	54	81	108	136	163	190	217	244	271
	Diff.	1	2	3	4	5	6	7	8	9	Diff.

N.	0	1	2	[redacted]	4	5	6	7	8	9	Diff.
160	204120	4391	4663	4934	5204	5475	5746	6016	6286	6556	271
161	6826	7096	7365	7634	7904	8173	8441	8710	8979	9247	269
162	9515	9783	*0051	*0319	*0586	*0853	*1121	*1388	*1654	*1921	267
163	212188	2454	2720	2986	3252	3518	3783	4049	4314	4579	266
164	4844	5109	5373	5638	5902	6166	6430	6694	6957	7221	264
165	217484	7747	8010	8273	8536	8798	9060	9323	9585	9846	262
166	220108	0370	0631	0892	1153	1414	1675	1936	2196	2456	261
167	2716	2976	3236	3496	3755	4015	4274	4533	4792	5051	259
168	5309	5568	5826	6084	6342	6600	6858	7115	7372	7630	258
169	7887	8144	8400	8657	8913	9170	9426	9682	9938	*0193	256
170	230449	0704	0960	1215	1470	1724	1979	2234	2488	2742	255
171	2996	3250	3504	3757	4011	4264	4517	4770	5023	5276	253
172	5528	5781	6033	6285	6537	6789	7041	7292	7544	7795	252
173	8046	8297	8548	8799	9049	9299	9550	9800	*0050	*0300	250
174	240549	0799	1048	1297	1546	1795	2044	2293	2541	2790	249
175	243038	3286	3534	3782	4030	4277	4525	4772	5019	5266	248
176	5513	5759	6006	6252	6499	6745	6991	7237	7482	7728	246
177	7973	8219	8464	8709	8954	9198	9443	9687	9932	*0176	245
178	250420	0664	0908	1151	1395	1638	1881	2125	2368	2610	243
179	2853	3096	3338	3580	3822	4064	4306	4548	4790	5031	242

N.	Diff.	1	2	3	4	5	6	7	8	9	Diff.
PROPORTIONAL PARTS	272	27	54	82	109	136	163	190	218	245	272
	271	27	54	81	108	136	163	190	217	244	271
	270	27	54	81	108	135	162	189	216	243	270
	269	27	54	81	108	135	161	188	215	242	269
	268	27	54	80	107	134	161	188	214	241	268
	267	27	53	80	107	134	160	187	214	240	267
	266	27	53	80	106	133	160	186	213	239	266
	265	27	53	80	106	133	159	186	212	239	265
	264	26	53	79	106	132	158	185	211	238	264
	263	26	53	79	105	132	158	184	210	237	263
	262	26	52	79	105	131	157	183	210	236	262
	261	26	52	78	104	131	157	183	209	235	261
	260	26	52	78	104	130	156	182	208	234	260
	259	26	52	78	104	130	155	181	207	233	259
	258	26	52	77	103	129	155	181	206	232	258
	257	26	51	77	103	129	154	180	206	231	[illegible]
	256	26	51	77	102	128	154	179	205	230	[illegible]
	255	26	51	77	102	128	153	179	204	230	255
	254	25	51	76	102	127	152	178	203	229	254
	253	25	51	76	101	127	152	177	202	228	253
	252	25	50	76	101	126	151	176	202	227	252
	251	25	50	75	100	126	151	176	201	226	251
	250	25	50	75	100	125	150	175	200	225	250
	249	25	50	[illegible]	100	125	149	174	199	224	249
	248	25	50	74	99	124	149	174	198	223	248
	247	25	49	74	99	124	148	173	198	222	247
	246	25	49	74	98	123	148	172	197	221	246
	245	25	49	74	98	123	147	172	196	221	245
	244	24	49	73	98	122	146	171	195	220	244
	243	24	49	73	97	122	146	170	194	219	243
	242	24	48	73	97	121	145	169	194	218	242
	241	24	48	72	96	121	145	169	193	217	241
	240	24	48	72	96	120	144	168	192	216	240
	Diff.	1	2	[redacted]	4	5	6	7	[redacted]	9	Diff.

N.	0	1	2	3	4	5	6	7	8	9	Diff.
180	255273	5514	5755	5996	6237	6477	6718	6958	7198	7439	241
181	7679	7918	8158	8398	8637	8877	9116	9355	9594	9833	239
182	260071	0310	0548	0787	1025	1263	1501	1739	1976	2214	238
183	2451	2688	2925	3162	3399	3636	3873	4109	4346	4582	237
184	4818	5054	5290	5525	5761	5996	6232	6467	6702	6937	235
185	267172	7406	7641	7875	8110	8344	8578	8812	9046	9279	234
186	9513	9746	9980	*0213	*0446	*0679	*0912	*1144	*1377	*1609	233
187	271842	2074	2306	2538	2770	3001	3233	3464	3696	3927	232
188	4158	4389	4620	4850	5081	5311	5542	5772	6002	6232	230
189	6462	6692	6921	7151	7380	7609	7838	8067	8296	8525	229
190	278754	8982	9211	9439	9667	9895	*0123	*0351	*0578	*0806	228
191	281033	1261	1488	1715	1942	2169	2396	2622	2849	3075	227
[redacted]	3301	3527	3753	3979	4205	4431	4656	4882	5107	5332	226
193	5557	5782	6007	6232	6456	6681	6905	7130	7354	7578	225
194	7802	8026	8249	8473	8696	8920	9143	9366	9589	9812	223
195	290035	0257	0480	0702	0925	1147	1369	1591	1813	2034	222
196	2256	2478	2699	2920	3141	3363	3584	3804	4025	4246	221
197	4466	4687	4907	5127	5347	5567	5787	6007	6226	6446	220
198	6665	6884	7104	7323	7542	7761	7979	8198	8416	8635	219
199	8853	9071	9289	9507	9725	9943	*0161	*0378	*0595	*0813	218
200	301030	1247	1464	1681	1898	2114	2331	2547	2764	2980	217
201	3196	3412	3628	3844	4059	4275	4491	4706	4921	5136	216
202	5351	5566	5781	5996	6211	6425	6639	6854	7068	7282	215
203	7496	7710	7924	8137	8351	8564	8778	8991	9204	9417	213
204	9630	9843	*0056	*0268	*0481	*0693	*0906	*1118	*1330	*1542	212

N.	Diff.	1	2	3	4	[redacted]	6	7	8	9	Diff
PROPORTIONAL PARTS	239	24	48	72	96	120	143	167	191	215	239
	238	24	48	71	95	119	143	167	190	214	238
	237	24	47	71	95	119	142	166	190	213	237
	236	24	47	71	94	118	142	165	189	212	236
	235	24	47	71	94	118	141	165	188	212	235
	234	23	47	70	94	117	140	164	187	211	234
	233	23	47	70	93	117	140	163	186	210	233
	232	23	46	70	93	116	139	162	186	209	232
	231	23	46	69	92	116	139	162	185	208	231
	230	23	46	69	92	115	138	161	184	207	230
	229	23	46	69	92	115	137	160	183	206	229
	228	23	46	68	91	114	137	160	182	205	228
	227	23	45	68	91	114	136	159	182	204	227
	226	23	45	68	90	113	136	158	181	203	226
	225	23	45	68	90	113	135	158	180	203	225
	224	22	45	67	90	112	134	157	179	202	224
	223	22	45	67	89	112	134	156	178	201	223
	222	22	44	67	89	111	133	155	178	200	222
	221	22	44	66	88	111	133	155	177	199	221
	220	22	44	[redacted]	88	110	132	154	176	198	220
	219	22	44	66	88	110	131	153	175	197	219
	218	22	44	65	87	109	131	153	174	196	218
	217	22	43	65	[redacted]	109	130	152	174	195	217
	216	22	43	65		108	130	151	173	194	216
	215	22	43	65	86	108	129	151	172	194	215
	214	21	43	64	86	107	128	150	171	193	214
	213	21	43	64	85	107	128	149	170	192	213
	212	21	42	64	85	106	127	148	170	191	212
	Diff.	1	2	3	4	5	6	7	8	[redacted]	Diff.

N.	0	1	2	3	4	5	6	7	8	9	Diff.
205	311754	1966	2177	2389	2600	2812	3023	3234	3445	3656	211
206	3867	4078	4289	4499	4710	4920	5130	5340	5551	5760	210
207	5970	6180	6390	6599	6809	7018	7227	7436	7646	7854	209
208	8063	8272	8481	8689	8898	9106	9314	9522	9730	9938	208
209	320146	0354	0562	0769	0977	1184	1391	1598	1805	2012	207
210	322219	2426	2633	2839	3046	3252	3458	3665	3871	4077	206
211	4282	4488	4694	4899	5105	5310	5516	5721	5926	6131	205
212	6336	6541	6745	6950	7155	7359	7563	7767	7972	8176	204
213	8380	8583	8787	8991	9194	9398	9601	9805	*0008	*0211	203
214	330414	0617	0819	1022	1225	1427	1630	1832	2034	2236	202
215	332438	2640	2842	3044	3246	3447	3649	3850	4051	4253	202
216	4454	4655	4856	5057	5257	5458	5658	5859	6059	6260	201
217	6460	6660	6860	7060	7260	7459	7659	7858	8058	8257	200
218	8456	8656	8855	9054	9253	9451	9650	9849	*0047	*0246	199
219	340444	0642	0841	1039	1237	1435	1632	1830	2028	2225	198
220	342423	2620	2817	3014	3212	3409	3606	3802	[illegible]	4196	197
221	4392	4589	4785	4981	5178	5374	5570	5766	5962	6157	196
222	6353	6549	6744	6939	7135	7330	7525	7720	7915	8110	195
223	8305	8500	8694	8889	9083	9278	9472	9666	9860	*0054	194
224	350248	0442	0636	0829	1023	1216	1410	1603	1796	1989	193
225	352183	2375	2568	2761	2954	3147	3339	3532	3724	3916	193
226	4108	4301	4493	4685	4876	5068	5260	5452	5643	5834	192
227	6026	6217	6408	6599	6790	6981	7172	7363	7554	7744	191
228	7935	8125	8316	8506	8696	8886	9076	9266	9456	9646	190
229	9835	*0025	*0215	*0404	*0593	*0783	*0972	*1161	*1350	*1539	189
230	361728	1917	2105	2294	2482	2671	2859	3048	3236	3424	188
231	3612	3800	3988	4176	4363	4551	4739	4926	5113	5301	188
232	5488	5675	5862	6049	6236	6423	6610	6796	6983	7169	187
233	7356	7542	7729	7915	8101	8287	8473	8659	8845	9030	186
234	9216	9401	9587	9772	9958	*0143	*0328	*0513	*0698	*0883	185

N.	Diff.	1	2	3	4	5	6	7	8	9	Diff.
PROPORTIONAL PARTS	212	21	42	64	85	106	127	148	170	191	212
	211	21	42	63	84	106	127	148	169	190	211
	210	21	42	63	84	105	126	147	168	189	210
	209	21	42	63	84	105	125	146	167	188	209
	208	21	42	62	83	104	125	146	166	187	208
	207	21	41	62	83	104	124	145	166	186	207
	206	21	41	62	82	103	124	144	165	185	206
	205	21	41	62	82	103	123	144	164	185	205
	204	20	41	61	82	102	122	143	163	184	204
	203	20	41	61	81	102	122	142	162	183	203
	202	20	40	61	81	101	121	141	162	182	202
	201	20	40	60	80	101	121	141	161	181	201
	200	20	40	60	80	100	120	140	160	180	200
	199	20	40	60	80	100	119	139	159	179	199
	198	20	40	59	79	99	119	139	158	178	198
	197	20	39	59	79	99	118	138	158	177	197
	196	20	39	59	78	98	118	137	157	176	196
	195	20	39	59	78	98	117	137	156	176	195
	194	19	39	58	78	97	116	136	155	175	194
	193	19	39	58	77	97	116	135	154	174	193
	192	19	38	58	77	96	115	134	154	173	192
	191	19	38	57	76	96	115	134	153	172	191
	190	19	38	57	76	95	114	133	152	171	190
	189	19	38	57	76	95	113	132	151	170	189
	188	19	38	56	75	94	113	132	150	169	188
	Diff.	1	2	3	4	5	6	7	8	9	Diff.

N.	0	1	2	3	4	5	6	7	8	9	Diff.
235	371068	1253	1437	1622	1806	1991	2175	2360	2544	2728	184
236	2912	3096	3280	3464	3647	3831	4015	4198	4382	4565	184
237	4748	4932	5115	5298	5481	5664	5846	6029	6212	6394	183
238	6577	6759	6942	7124	7306	7488	7670	7852	8034	8216	182
239	8398	8580	8761	8943	9124	9306	9487	9668	9849	*0030	181
240	380211	0392	0573	0754	0934	1115	1296	1476	1656	1837	181
241	2017	2197	2377	2557	2737	2917	3097	3277	3456	3636	180
242	3815	3995	4174	4353	4533	4712	4891	5070	5249	5428	179
243	5606	5785	5964	6142	6321	6499	6677	6856	7034	7212	178
244	7390	7568	7746	7923	8101	8279	8456	8634	8811	8989	178
245	389166	9343	9520	9698	9875	*0051	*0228	*0405	*0582	*0759	177
246	390935	1112	1288	1464	1641	1817	1993	2169	2345	2521	176
247	2697	2873	3048	3224	3400	3575	3751	3926	4101	4277	176
248	4452	4627	4802	4977	5152	5326	5501	5676	5850	6025	175
249	6199	6374	6548	6722	6896	7071	7245	7419	7592	7766	174
250	397940	8114	8287	8461	8634	8808	8981	9154	9328	9501	173
251	9674	9847	*0020	*0192	*0365	*0538	*0711	*0883	*1056	*1228	173
252	401401	1573	1745	1917	2089	2261	2433	2605	2777	2949	172
253	3121	3292	3464	3635	3807	3978	4149	4320	4492	4663	171
254	4834	5005	5176	5346	5517	5688	5858	6029	6199	6370	171
255	406540	6710	6881	7051	7221	7391	7561	7731	7901	8070	170
256	8240	8410	8579	8749	8918	9087	9257	9426	9595	9764	169
257	9933	*0102	*0271	*0440	*0609	*0777	*0946	*1114	*1283	*1451	169
258	411620	1788	1956	2124	2293	2461	2629	2796	2964	3132	168
259	3300	3467	3635	3803	3970	4137	4305	4472	4639	4806	167
260	414973	5140	5307	5474	5641	5808	5974	6141	6308	6474	167
261	6641	6807	6973	7139	7306	7472	7638	7804	7970	8135	166
262	8301	8467	8633	8798	8964	9129	9295	9460	9625	9791	165
263	9956	*0121	*0286	*0451	*0616	*0781	*0945	*1110	*1275	*1439	165
264	421604	1768	1933	2097	2261	2426	2590	2754	2918	3082	164

N.	Diff.	1	2	3	4	5	6	7	8	9	Diff.
PROPORTIONAL PARTS	187	19	37	56	75	94	112	131	150	168	187
	186	19	37	56	74	93	112	130	149	167	186
	185	19	37	56	74	93	111	130	148	167	185
	184	18	37	55	74	92	110	129	147	166	184
	183	18	37	55	73	92	110	128	146	165	183
	182	18	36	55	73	91	109	127	146	164	182
	181	18	36	54	72	91	109	127	145	163	181
	180	18	36	54	72	90	108	126	144	162	180
	179	18	36	54	72	90	107	125	143	161	179
	178	18	36	53	71	89	107	125	142	160	178
	177	18	35	53	71	89	106	124	142	159	177
	176	18	35	53	70	88	106	123	141	158	176
	175	18	35	53	70	88	105	123	140	158	175
	174	17	35	52	70	87	104	122	139	157	174
	173	17	35	52	69	87	104	121	138	156	173
	172	17	34	52	69	86	103	120	138	155	172
	171	17	34	51	68	86	103	120	137	154	171
	170	17	34	51	68	85	102	119	136	153	170
	169	17	34	51	68	85	101	118	135	152	169
	168	17	34	50	67	84	101	118	134	151	168
	167	17	33	50	67	84	100	117	134	150	167
	166	17	33	50	66	83	100	116	133	149	166
	165	17	33	50	66	83	99	116	132	149	165
	164	16	33	49	66	82	98	115	131	148	164
	Diff.	1	2	3	4	5	6	7	8	9	Diff.

0	1	2	3	4	5	6	7	8	9	Diff.
423246	3410	3574	3737	3901	4065	4228	4392	4555	4718	164
4882	5045	5208	5371	5534	5697	5860	6023	6186	6349	163
6511	6674	6836	6999	7161	7324	7486	7648	7811	7973	162
8135	8297	8459	8621	8783	8944	9106	9268	9429	9591	162
9752	9914	*0075	*0236	*0398	*0559	*0720	*0881	*1042	*1203	161
431364	1525	1685	1846	2007	2167	2328	2488	2649	2809	161
2969	3130	3290	3450	3610	3770	3930	4090	4249	4409	160
4569	4729	4888	5048	5207	5367	5526	5685	5844	6004	159
6163	6322	6481	6640	6799	6957	7116	7275	7433	7592	159
7751	7909	8067	8226	8384	8542	8701	8859	9017	9175	158
439333	9491	9648	9806	9964	*0122	*0279	*0437	*0594	*0752	158
440909	1066	1224	1381	1538	1695	1852	2009	2166	2323	157
2480	2637	2793	2950	3106	3263	3419	3576	3732	3889	157
4045	4201	4357	4513	4669	4825	4981	5137	5293	5449	156
5604	5760	5915	6071	6226	6382	6537	6692	6848	7003	155
447158	7313	7468	7623	7778	7933	8088	8242	8397	8552	155
8706	8861	9015	9170	9324	9478	9633	9787	9941	*0095	154
450249	0403	0557	0711	0865	1018	1172	1326	1479	1633	154
1786	1940	2093	2247	2400	2553	2706	2859	3012	3165	153
3318	3471	3624	3777	3930	4082	4235	4387	4540	4692	153
454845	4997	5150	5302	5454	5606	5758	5910	6062	6214	152
6366	6518	6670	6821	6973	7125	7276	7428	7579	7731	152
7882	8033	8184	8336	8487	8638	8789	8940	9091	9242	151
9392	9543	9694	9845	9995	*0146	*0296	*0447	*0597	*0748	151
460898	1048	1198	1348	1499	1649	1799	1948	2098	2248	150
462398	2548	2697	2847	2997	3146	3296	3445	3594	3744	150
3893	4042	4191	4340	[illegible]	4639	4788	4936	5085	5234	149
5383	5532	5680	5829	5977	6126	6274	6423	6571	6719	149
6868	7016	7164	7312	7460	7608	7756	7904	8052	8200	148
8347	8495	8643	8790	8938	9085	9233	9380	9527	9675	148
469822	9969	*0116	*0263	*0410	*0557	*0704	*0851	*0998	*1145	147
471292	1438	1585	1732	1878	2025	2171	2318	2464	2610	146
2756	2903	3049	3195	3341	3487	3633	3779	3925	4071	146
4216	4362	4508	4653	4799	4944	5090	5235	5381	5526	146
5671	5816	5962	6107	6252	6397	6542	6687	6832	6976	145

Diff.	1	2	3	4	5	6	7	8	9	Diff.
164	16	33	49	66	82	98	115	131	148	164
163	16	33	49	65	82	98	114	130	147	163
162	16	32	49	65	81	97	113	130	146	162
161	16	32	48	64	81	97	113	129	145	161
160	16	32	48	64	80	96	112	128	144	160
159	16	32	48	64	80	95	111	127	143	159
158	16	32	47	63	79	95	111	126	142	158
157	16	31	47	63	79	[illegible]	110	126	141	157
156	16	31	47	62	78	94	109	125	140	156
155	16	31	47	62	78	93	[illegible]	124	140	155
154	15	31	46	62	77	92	[illegible]	123	139	154
153	15	31	46	61	77	92	107	122	138	153
152	15	30	46	61	76	91	106	122	137	152
151	15	30	45	60	76	91	106	121	136	151
150	15	30	45	60	75	90	105	120	135	150
149	15	30	45	60	75	89	104	119	134	149
148	15	30	44	59	74	89	104	118	133	148
147	15	29	[illegible]	59	74	88	[illegible]	118	132	147
146	15	29	[illegible]	58	73	88	[illegible]	117	131	146
145	15	29	44	58	73	87	102	116	131	145
144	14	29	43	58	72	86	101	115	130	144
143	14	29	43	57	72	86	100	114	129	143
Diff.	1	2	3	4	5	6	7	8	9	Diff.

N.	0	1	2	3	4	5	6	7	8	9	Diff
300	477121	7266	7411	7555	7700	7844	7989	8133	8278	8422	145
301	8566	8711	8855	8999	9143	9287	9431	9575	9719	9863	144
302	480007	0151	0294	0438	0582	0725	0869	1012	1156	[illegible]	144
303	1443	1586	1729	1872	2016	2159	2302	2445	2588	2731	143
304	2874	3016	3159	3302	3445	3587	3730	3872	4015	4157	143
305	484300	4442	4585	4727	4869	5011	5153	5295	5437	5579	142
306	5721	5863	6005	6147	6289	6430	6572	6714	6855	6997	142
307	7138	7280	7421	7563	7704	7845	7986	8127	8269	8410	141
308	8551	8692	8833	8974	9114	9255	9396	9537	9677	9818	141
309	9958	*0099	*0239	*0380	*0520	*0661	*0801	*0941	*1081	*1222	140
310	491362	1502	1642	1782	1922	2062	2201	2341	2481	2621	140
311	2760	2900	3040	3179	3319	3458	3597	3737	3876	4015	139
312	4155	4294	4433	4572	4711	4850	4989	5128	5267	5406	139
313	5544	5683	5822	5960	6099	6238	6376	6515	6653	6791	139
314	6930	7068	7206	7344	7483	7621	7759	7897	8035	8173	138
315	498311	8448	8586	8724	8862	8999	9137	9275	9412	9550	138
316	9687	9824	9962	*0099	*0236	*0374	*0511	*0648	*0785	*0922	137
317	501059	1196	1333	1470	1607	1744	1880	2017	2154	2291	137
318	2427	2564	2700	2837	2973	3109	3246	3382	3518	3655	136
319	3791	3927	4063	4199	4335	4471	4607	4743	4878	5014	136
320	505150	5286	5421	5557	5693	5828	5964	6099	6234	6370	136
321	6505	6640	6776	6911	7046	7181	7316	7451	7586	7721	135
322	7856	7991	8126	8260	8395	8530	8664	8799	8934	9068	135
323	9203	9337	9471	9606	9740	9874	*0009	*0143	*0277	*0411	134
324	510545	0679	0813	0947	1081	1215	1349	1482	2616	1750	134
325	511883	2017	2151	2284	2418	2551	2684	2818	2951	3084	133
326	3218	3351	3484	3617	3750	3883	4016	4149	4282	4415	133
327	4548	4681	4813	4946	5079	5211	5344	5476	5609	5741	133
328	5874	6006	6139	6271	6403	6535	6668	6800	6932	7064	132
329	7196	7328	7460	7592	7724	7855	7987	8119	8251	8382	132
330	518514	8646	8777	8909	9040	9171	9303	9434	9566	9697	131
331	9828	9959	*0090	*0221	*0353	*0484	*0615	*0745	*0876	*1007	131
332	521138	1269	1400	1530	1661	1792	1922	2053	2183	2314	131
333	2444	2575	2705	2835	2966	3096	3226	3356	3486	3616	130
334	3746	3876	4006	4136	4266	4396	4526	4656	4785	4915	130
335	525045	5174	5304	5434	5563	5693	5822	5951	6081	6210	129
336	6339	6469	6598	6727	6856	6985	7114	7243	7372	7501	129
337	7630	7759	7888	8016	8145	8274	8402	8531	8660	8788	129
338	8917	9045	9174	9302	9430	9559	9687	9815	9943	*0072	128
339	530200	0328	0456	0584	0712	0840	0968	1096	1223	1351	128

N.	Diff.	1	2	3	4	5	6	7	8	9	Diff.
PROPORTIONAL PARTS	142	14	28	43	57	71	85	99	114	128	142
	141	14	28	42	56	71	85	99	113	127	141
	140	14	28	42	56	70	84	98	112	126	140
	139	14	28	42	56	70	83	97	111	125	139
	138	14	28	41	55	69	83	97	110	124	138
	137	14	27	41	55	69	82	96	110	123	137
	136	14	27	41	54	68	82	95	109	122	136
	135	14	27	41	54	68	81	95	108	122	135
	134	13	27	40	54	67	[illegible]	94	107	121	134
	133	13	27	40	53	67	80	[illegible]	106	120	133
	132	13	26	40	53	66	79	92	106	119	132
	131	13	26	39	52	66	79	92	105	118	131
	130	13	26	39	52	65	78	91	104	117	130
	129	13	26	39	52	65	77	90	103	116	129
	128	13	26	38	51	64	77	90	102	115	128
	127	13	25	38	51	64	76	89	102	114	127
	Diff.	1	2	3	4	5	6	7	8	9	Diff.

0	1	2	3	4	5	6	7	8	9	Diff.
531479	1607	1734	1862	1990	2117	2245	2372	2500	2627	128
2754	2882	3009	3136	3264	3391	3518	3645	3772	3899	127
4026	4153	4280	4407	4534	4661	4787	4914	5041	5167	127
5294	5421	5547	5674	5800	5927	6053	6180	6306	6432	126
6558	6685	6811	6937	7063	7189	7315	7441	7567	7693	126
537819	7945	8071	8197	8322	8448	8574	8699	8825	8951	126
9076	9202	9327	9452	9578	9703	9829	9954	*0079	*0204	125
540329	0455	0580	0705	0830	0955	1080	1205	1330	1454	125
1579	1704	1829	1953	2078	2203	2327	2452	2576	2701	125
2825	2950	3074	3199	3323	3447	3571	3696	3820	3944	124
544068	4192	4316	4440	4564	4688	4812	4936	5060	5183	124
5307	5431	5555	5678	5802	5925	6049	6172	6296	6419	124
6543	6666	6789	6913	7036	7159	7282	7405	7529	7652	123
7775	7898	8021	8144	8267	8389	8512	8635	8758	8881	123
9003	9126	9249	9371	9494	9616	9739	9861	9984	*0106	123
550228	0351	0473	0595	0717	0840	0962	1084	1206	1328	122
1450	1572	1694	1816	1938	2060	2181	2303	2425	2547	122
2668	2790	2911	3033	3155	3276	3398	3519	3640	3762	121
3883	4004	4126	4247	4368	4489	4610	4731	4852	4973	121
5094	5215	5336	5457	5578	5699	5820	5940	6061	6182	121
556303	6423	6544	6664	6785	6905	7026	7146	7267	7387	120
7507	7627	7748	7868	7988	8108	8228	8349	8469	8589	120
8709	8829	8948	9068	9188	9308	9428	9548	9667	9787	120
9907	*0026	*0146	*0265	*0385	*0504	*0624	*0743	*0863	*0982	119
561101	1221	1340	1459	1578	1698	1817	1936	2055	2174	119
562293	2412	2531	2650	2769	2887	3006	3125	3244	3362	119
3481	3600	3718	3837	3955	4074	4192	4311	4429	4548	119
4666	4784	4903	5021	5139	5257	5376	5494	5612	5730	118
5848	5966	6084	6202	6320	6437	6555	6673	6791	6909	118
7026	7144	7262	7379	7497	7614	7732	7849	7967	8084	118
568202	8319	8436	8554	8671	8788	8905	9023	9140	9257	117
9374	9491	9608	9725	9842	9959	*0076	*0193	*0309	*0426	117
570543	0660	0776	0893	1010	1126	1243	1359	1476	1592	117
1709	1825	1942	2058	2174	2291	2407	2523	2639	2755	116
2872	2988	3104	3220	3336	3452	3568	3684	3800	3915	116
574031	4147	4263	4379	4494	4610	4726	4841	4957	5072	116
5188	5303	5419	5534	5650	5765	5880	5996	6111	6226	115
6341	6457	6572	6687	6802	6917	7032	7147	7262	7377	115
7492	7607	7722	7836	7951	8066	8181	8295	8410	8525	115
8639	8754	8868	8983	9097	9212	9326	9441	9555	9669	114

Diff.	1	2	3	4	5	6	7	8	9	Diff.
128	13	26	38	51	64	77	90	102	115	128
127	13	25	38	51	64	76	89	102	114	127
126	13	25	38	50	63	76	88	101	113	126
125	13	25	38	50	63	75	88	100	113	125
124	12	25	37	50	62	74	87	99	112	124
123	12	25	37	49	62	74	86	98	111	123
122	12	24	37	49	61	73	85	98	110	122
121	12	24	36	48	61	73	85	97	109	121
120	12	24	36	48	60	72	84	96	108	120
119	12	24	36	48	60	71	83	95	107	119
118	12	24	35	47	59	71	83	94	106	118
117	12	23	35	47	59	70	82	94	105	117
116	12	23	35	46	58	70	81	93	104	116
Diff.	1	2	3	4	5	6	7	8	9	Diff.

N.	0	1	2	3	4	5	6	7	8	9	Diff.
380	579784	9898	*0012	*0126	*0241	*0355	*0469	*0583	*0697	*0811	114
381	580925	1039	1153	1267	1381	1495	1608	1722	1836	1950	114
382	2063	2177	2291	2404	2518	2631	2745	2858	2972	3085	114
383	3199	3312	3426	3539	3652	3765	3879	3992	4105	4218	113
384	4331	4444	4557	4670	4783	4896	5009	5122	5235	5348	113
385	585461	5574	5686	5799	5912	6024	6137	6250	6362	6475	113
386	6587	6700	6812	6925	7037	7149	7262	7374	7486	7599	112
387	7711	7823	7935	8047	8160	8272	8384	8496	8608	8720	112
388	8832	8944	9056	9167	9279	9391	9503	9615	9726	9838	112
389	9950	*0061	*0173	*0284	*0396	*0507	*0619	*0730	*0842	*0953	112
390	591065	1176	1287	1399	1510	1621	1732	1843	1955	2066	111
391	2177	2288	2399	2510	2621	2732	2843	2954	3064	3175	111
392	3286	3397	3508	3618	3729	3840	3950	4061	4171	4282	111
393	4393	4503	4614	4724	4834	4945	5055	5165	5276	5386	110
394	5496	5606	5717	5827	5937	6047	6157	6267	6377	6487	110
395	596597	6707	6817	6927	7037	7146	7256	7366	7476	7586	110
396	7695	7805	7914	8024	8134	8243	8353	8462	8572	8681	110
397	8791	8900	9009	9119	9228	9337	9446	9556	9665	9774	109
398	9883	9992	*0101	*0210	*0319	*0428	*0537	*0646	*0755	*0864	109
399	600973	1082	1191	1299	1408	1517	1625	1734	1843	1951	109
400	602060	2169	2277	2386	2494	2603	2711	2819	2928	3036	108
401	3144	3253	3361	3469	3577	3686	3794	3902	4010	4118	108
402	4226	4334	[illegible]	4550	4658	4766	4874	4982	5089	5197	108
403	5305	5413	5521	5628	5736	5844	5951	6059	6166	6274	108
404	6381	6489	6596	6704	6811	6919	7026	7133	7241	7348	107
405	607455	7562	7669	7777	7884	7991	8098	8205	8312	8419	107
406	8526	8633	8740	8847	8954	9061	9167	9274	9381	9488	107
407	9594	9701	9808	9914	*0021	*0128	*0234	*0341	*0447	*0554	107
408	610660	0767	0873	0979	1086	1192	1298	1405	1511	1617	106
409	1723	1829	1936	2042	2148	2254	2360	2466	2572	2678	106
410	612784	2890	2996	3102	3207	3313	3419	3525	3630	3736	106
411	3842	3947	4053	4159	4264	4370	4475	4581	4686	4792	106
412	4897	5003	5108	5213	5319	5424	5529	5634	5740	5845	105
413	5950	6055	6160	6265	6370	6476	6581	6686	6790	6895	105
414	7000	7105	7210	7315	7420	7525	7629	7734	7839	7943	105
415	618048	8153	8257	8362	8466	8571	8676	8780	8884	8989	105
416	9093	9198	9302	9406	9511	9615	9719	9824	9928	*0032	104
417	620136	0240	0344	0448	0552	0656	0760	0864	0968	1072	104
418	1176	1280	1384	1488	1592	1695	1799	1903	2007	2110	104
419	2214	2318	2421	2525	2628	2732	2835	2939	3042	3146	104

N.	Diff.	1	2	[illegible]	4	[illegible]	6	7	[illegible]	9	[illegible]
PROP. PARTS	115	12	23	35	46	58	69	81	92	104	115
	114	11	23	34	46	57	68	80	91	103	114
	113	11	23	34	45	57	68	79	90	102	113
	112	11	22	34	45	56	67	78	90	101	112
	111	11	22	33	44	56	67	78	89	100	111
	110	11	22	33	44	55	66	77	88	99	110
	109	11	22	33	44	55	65	76	87	98	109
	108	11	22	32	43	54	65	76	86	97	108
	107	11	21	32	43	54	64	75	86	96	107
	106	11	21	32	42	53	64	74	85	95	106
	105	11	21	32	42	53	63	74	84	95	105
	104	10	21	31	42	52	62	73	83	94	104
	103	10	21	31	41	52	62	72	82	93	103
	Diff.	1	2	3	4	5	6	7	[illegible]	9	Diff.

N.	0	1	2	3	4	5	6	7	8	9	Diff.
420	623249	3353	3456	3559	3663	3766	3869	3973	4076	4179	103
421	4282	4385	4488	4591	4695	4798	4901	5004	5107	5210	103
422	5312	5415	5518	5621	5724	5827	5929	6032	6135	6238	103
423	6340	6443	6546	6648	6751	6853	6956	7058	7161	7263	103
424	7366	7468	7571	7673	7775	7878	7980	8082	8185	8287	102
425	628389	8491	8593	8695	8797	8900	9002	9104	9206	9308	102
426	9410	9512	9613	9715	9817	9919	*0021	*0123	*0224	*0326	102
427	630428	0530	0631	0733	0835	0936	1038	1139	1241	1342	102
428	1444	1545	1647	1748	1849	1951	2052	2153	2255	2356	101
429	2457	2559	2660	2761	2862	2963	3064	3165	3266	3367	101
430	633468	3569	3670	3771	3872	3973	4074	4175	4276	4376	101
431	4477	4578	4679	4779	4880	4981	5081	5182	5283	5383	101
432	5484	5584	5685	5785	5886	5986	6087	6187	6287	6388	100
433	6488	6588	6688	6789	6889	6989	7089	7189	7290	7390	100
434	7490	7590	7690	7790	7890	7990	8090	8190	8290	8389	100
435	638489	8589	8689	8789	8888	8988	9088	9188	9287	9387	100
436	9486	9586	9686	9785	9885	9984	*0084	*0183	*0283	*0382	99
437	640481	0581	0680	0779	0879	0978	1077	1177	1276	1375	99
438	1474	1573	1672	1771	1871	1970	2069	2168	2267	2366	99
439	2465	2563	2662	2761	2860	2959	3058	3156	3255	3354	99
440	643453	3551	3650	3749	3847	3946	4044	4143	4242	4340	98
441	4439	4537	4636	4734	4832	4931	5029	5127	5226	5324	98
442	5422	5521	5619	5717	5815	5913	6011	6110	6208	6306	98
443	6404	6502	6600	6698	6796	6894	6992	7089	7187	7285	98
444	7383	7481	7579	7676	7774	7872	7969	8067	8165	8262	98
445	648360	8458	8555	8653	8750	8848	8945	9043	9140	9237	97
446	9335	9432	9530	9627	9724	9821	9919	*0016	*0113	*0210	97
447	650308	0405	0502	0599	0696	0793	0890	0987	1084	1181	97
448	1278	1375	1472	1569	1666	1762	1859	1956	2053	2150	97
449	2246	2343	2440	2536	2633	2730	2826	2923	3019	3116	97
450	653213	3309	3405	3502	3598	3695	3791	3888	3984	4080	96
451	4177	4273	4369	4465	4562	4658	4754	4850	4946	5042	96
452	5138	5235	5331	5427	5523	5619	5715	5810	5906	6002	96
453	6098	6194	6290	6386	6482	6577	6673	6769	6864	6960	96
454	7056	7152	7247	7343	7438	7534	7629	7725	7820	7916	96
455	658011	8107	8202	8298	8393	8488	8584	8679	8774	8870	95
456	8965	9060	9155	9250	9346	9441	9536	9631	9726	9821	95
457	9916	*0011	*0106	*0201	*0296	*0391	*0486	*0581	*0676	*0771	95
458	660865	0960	1055	1150	1245	1339	1434	1529	1623	1718	95
459	1813	1907	2002	2096	2191	2286	2380	2475	2569	2663	95
460	662758	2852	2947	3041	3135	3230	3324	3418	3512	3607	94
461	3701	3795	3889	3983	4078	4172	4266	4360	4454	4548	94
462	4642	4736	4830	4924	5018	5112	5206	5299	5393	5487	94
463	5581	5675	5769	5862	5956	6050	6143	6237	6331	6424	94
464	6518	6612	6705	6799	6892	6986	7079	7173	7266	7360	94

N.	Diff.	1	2	3	4	5	6	7	8	9	Diff.
PROP. PARTS	104	10	21	31	42	52	62	73	83	94	104
	103	10	21	31	41	52	62	72	82	93	103
	102	10	20	31	41	51	61	71	82	92	102
	101	10	20	30	40	51	61	71	81	91	101
	100	10	20	30	40	50	60	70	80	90	100
	99	10	20	30	40	50	59	69	79	89	99
	98	10	20	29	39	49	59	69	78	88	98
	97	10	19	29	39	49	58	68	78	87	97
	96	10	19	29	38	48	58	67	77	86	96
	95	10	19	29	38	48	57	67	76	86	95
	Diff.	1	2	3	4	5	6	7	8	9	Diff.

N.	0	1	2	3	4	5	6	7	8	9	Diff.
465	667453	7546	7640	7733	7826	7920	8013	8106	8199	8293	93
466	8386	8479	8572	8665	8759	8852	8945	9038	9131	9224	93
467	9317	9410	9503	9596	9689	9782	9875	9967	*0060	*0153	93
468	670246	0339	0431	0524	0617	0710	0802	0895	0988	1080	93
469	1173	1265	1358	1451	1543	1636	1728	1821	1913	2005	93
470	672098	2190	2283	2375	2467	2560	2652	2744	2836	2929	92
471	3021	3113	3205	3297	3390	3482	3574	3666	3758	3850	92
472	3942	4034	4126	4218	4310	4402	4494	4586	4677	4769	92
473	4861	4953	5045	5137	5228	5320	5412	5503	5595	5687	92
474	5778	5870	5962	6053	6145	6236	6328	6419	6511	6602	92
475	676694	6785	6876	6968	7059	7151	7242	7333	7424	7516	91
476	7607	7698	7789	7881	7972	8063	8154	8245	8336	8427	91
477	8518	8609	8700	8791	8882	8973	9064	9155	9246	9337	91
478	9428	9519	9610	9700	9791	9882	9973	*0063	*0154	*0245	91
479	680336	0426	0517	0607	0698	0789	0879	0970	1060	1151	91
480	681241	1332	1422	1513	1603	1693	1784	1874	1964	2055	90
481	2145	2235	2326	2416	2506	2596	2686	2777	2867	2957	90
482	3047	3137	3227	3317	3407	3497	3587	3677	3767	3857	90
483	3947	4037	4127	4217	4307	4396	4486	4576	4666	4756	90
484	4845	4935	5025	5114	5204	5294	5383	5473	5563	5652	90
485	685742	5831	5921	6010	6100	6189	6279	6368	6458	6547	89
486	6636	6726	6815	6904	6994	7083	7172	7261	7351	7440	89
487	7529	7618	7707	7796	7886	7975	8064	8153	8242	8331	89
488	8420	8509	8598	8687	8776	8865	8953	9042	9131	9220	89
489	9309	9398	9486	9575	9664	9753	9841	9930	*0019	*0107	89
490	690196	0285	0373	0462	0550	0639	0728	0816	0905	0993	89
491	1081	1170	1258	1347	1435	1524	1612	1700	1789	1877	88
492	1965	2053	2142	2230	2318	2406	2494	2583	2671	2759	88
493	2847	2935	3023	3111	3199	3287	3375	3463	3551	3639	88
494	3727	3815	3903	3991	4078	4166	4254	4342	4430	4517	88
495	694605	4693	4781	4868	4956	5044	5131	5219	5307	5394	88
496	5482	5569	5657	5744	5832	5919	6007	6094	6182	6269	87
497	6356	6444	6531	6618	6706	6793	6880	6968	7055	7142	87
498	7229	7317	7404	7491	7578	7665	7752	7839	7926	8014	87
499	8101	8188	8275	8362	8449	8535	8622	8709	8796	8883	87
500	698970	9057	9144	9231	9317	9404	9491	9578	9664	9751	87
501	9838	9924	*0011	*0098	*0184	*0271	*0358	*0444	*0531	*0617	87
502	700704	0790	0877	0963	1050	1136	1222	1309	1395	1482	86
503	1568	1654	1741	1827	1913	1999	2086	2172	2258	2344	86
504	2431	2517	2603	2689	2775	2861	2947	3033	3119	3205	86
505	703291	3377	3463	3549	3635	3721	3807	3893	3979	4065	86
506	4151	4236	4322	4408	4494	4579	4665	4751	4837	4922	86
507	5008	5094	5179	5265	5350	5436	5522	5607	5693	5778	86
508	5864	5949	6035	6120	6206	6291	6376	6462	6547	6632	85
509	6718	6803	6888	6974	7059	7144	7229	7315	7400	7485	85

PROP. PARTS

N.	Diff.	1	2	3	4	5	6	7	8	9	Diff.
	94	9	19	28	38	47	56	66	75	85	94
	93	9	19	28	37	47	56	65	74	84	93
	92	9	18	28	37	46	55	64	74	83	92
	91	9	18	27	36	46	55	64	73	82	91
	90	9	18	27	36	45	54	63	72	81	90
	89	9	18	27	36	45	53	62	71	80	89
	88	9	18	26	35	44	53	62	70	79	88
	87	9	17	26	35	44	52	61	70	78	87
	86	9	17	26	34	43	52	60	69	77	86
	85	9	17	26	34	43	51	60	68	77	85
	Diff.	1	2	3	4	5	6	7	8	9	Diff.

N.	0	1	2	3	4	5	6	7	8	9	DIF.
510	707570	7655	7740	7826	7911	7996	8081	8166	8251	8336	85
511	8421	8506	8591	8676	8761	8846	8931	9015	9100	9185	85
512	9270	9355	9440	9524	9609	9694	9779	9863	9948	*0033	85
513	710117	0202	0287	0371	0456	0540	0625	0710	0794	0879	85
514	0963	1048	1132	1217	1301	1385	1470	1554	1639	1723	84
515	711807	1892	1976	2060	2144	2229	2313	2397	2481	2566	84
516	2650	2734	2818	2902	2986	3070	3154	3238	3323	3407	84
517	3491	3575	3659	3742	3826	3910	3994	4078	4162	4246	84
518	4330	4414	4497	4581	4665	4749	4833	4916	5000	5084	84
519	5167	5251	5335	5418	5502	5586	5669	5753	5836	5920	84
520	716003	6087	6170	6254	6337	6421	6504	6588	6671	6754	83
521	6838	6921	7004	7088	7171	7254	7338	7421	7504	7587	83
522	7671	7754	7837	7920	8003	8086	8169	8253	8336	8419	83
523	8502	8585	8668	8751	8834	8917	9000	9083	9165	9248	83
524	9331	9414	9497	9580	9663	9745	9828	9911	9994	*0077	83
525	720159	0242	0325	0407	0490	0573	0655	0738	0821	0903	83
526	0986	1068	1151	1233	1316	1398	1481	1563	1646	1728	82
527	1811	1893	1975	2058	2140	2222	2305	2387	2469	2552	82
528	2634	2716	2798	2881	2963	3045	3127	3209	3291	3374	82
529	3456	3538	3620	3702	3784	3866	3948	4030	4112	4194	82
530	724276	4358	4440	4522	4604	4685	4767	4849	4931	5013	82
531	5095	5176	5258	5340	5422	5503	5585	5667	5748	5830	82
532	5912	5993	6075	6156	6238	6320	6401	6483	6564	6646	82
533	6727	6809	6890	6972	7053	7134	7216	7297	7379	7460	81
534	7541	7623	7704	7785	7866	7948	8029	8110	8191	8273	81
535	728354	8435	8516	8597	8678	8759	8841	8922	9003	9084	81
536	9165	9246	9327	9408	9489	9570	9651	9732	9813	9893	81
537	9974	*0055	*0136	*0217	*0298	*0378	*0459	*0540	*0621	*0702	81
538	730782	0863	0944	1024	1105	1186	1266	1347	1428	1508	81
539	1589	1669	1750	1830	1911	1991	2072	2152	2233	2313	81
540	732394	2474	2555	2635	2715	2796	2876	2956	3037	3117	80
541	3197	3278	3358	3438	3518	3598	3679	3759	3839	3919	80
542	3999	4079	4160	4240	4320	4400	4480	4560	4640	4720	80
543	4800	4880	4960	5040	5120	5200	5279	5359	5439	5519	80
544	5599	5679	5759	5838	5918	5998	6078	6157	6237	6317	80
545	736397	6476	6556	6635	6715	6795	6874	6954	7034	7113	80
546	7193	7272	7352	7431	7511	7590	7670	7749	7829	7908	79
547	7987	8067	8146	8225	8305	8384	8463	8543	8622	8701	79
548	8781	8860	8939	9018	9097	9177	9256	9335	9414	9493	79
549	9572	9651	9731	9810	9889	9968	*0047	*0126	*0205	*0284	79
550	740363	0442	0521	0600	0678	0757	0836	0915	0994	1073	79
551	1152	1230	1309	1388	1467	1546	1624	1703	1782	1860	79
552	1939	2018	2096	2175	2254	2332	2411	2489	2568	2647	79
553	2725	2804	2882	2961	3039	3118	3196	3275	3353	3431	78
554	3510	3588	3667	3745	3823	3902	3980	4058	4136	4215	78
N.	DIF.	1	2	3	4	5	6	7	8	9	DIF.
PROP. PARTS	86	9	17	26	34	43	52	60	69	77	86
	85	9	17	26	34	43	51	60	68	77	85
	84	8	17	25	34	42	50	59	67	76	84
	83	8	17	25	33	42	50	58	66	75	83
	82	8	16	25	33	41	49	57	66	74	82
	81	8	16	24	32	41	49	57	65	73	81
	80	8	16	24	32	40	48	56	64	72	80
	79	8	16	24	32	40	47	55	63	71	79
	DIF.	1	2	3	4	5	6	7	8	9	DIF.

N.	0	1	2	3	4	5	6	7	8	9	Diff.
555	744293	4371	4449	4528	4606	4684	4762	4840	4919	4997	78
556	5075	5153	5231	5309	5387	5465	5543	5621	5699	5777	78
557	5855	5933	6011	6089	6167	6245	6323	6401	6479	6556	78
558	6634	6712	6790	6868	6945	7023	7101	7179	7256	7334	78
559	7412	7489	7567	7645	7722	7800	7878	7955	8033	8110	78
560	748188	8266	8343	8421	8498	8576	8653	8731	8808	8885	77
561	8963	9040	9118	9195	9272	9350	9427	9504	9582	9659	77
562	9736	9814	9891	9968	*0045	*0123	*0200	*0277	*0354	*0431	77
563	750508	0586	0663	0740	0817	0894	0971	1048	1125	1202	77
564	1279	1356	1433	1510	1587	1664	1741	1818	1895	1972	77
565	752048	2125	2202	2279	2356	2433	2509	2586	2663	2740	77
566	2816	2893	2970	3047	3123	3200	3277	3353	3430	3506	77
567	3583	3660	3736	3813	3889	3966	4042	4119	4195	4272	77
568	4348	4425	4501	4578	4654	4730	4807	4883	4960	5036	76
569	5112	5189	5265	5341	5417	5494	5570	5646	5722	5799	76
570	755875	5951	6027	6103	6180	6256	6332	6408	6484	6560	76
571	6636	6712	6788	6864	6940	7016	7092	7168	7244	7320	76
572	7396	7472	7548	7624	7700	7775	7851	7927	8003	8079	76
573	8155	8230	8306	8382	8458	8533	8609	8685	8761	8836	76
574	8912	8988	9063	9139	9214	9290	9366	9441	9517	9592	76
575	759668	9743	9819	9894	9970	*0045	*0121	*0196	*0272	*0347	75
576	760422	0498	0573	0649	0724	0799	0875	0950	1025	1101	75
577	1176	1251	1326	1402	1477	1552	1627	1702	1778	1853	75
578	1928	2003	2078	2153	2228	2303	2378	2453	2529	2604	75
579	2679	2754	2829	2904	2978	3053	3128	3203	3278	3353	75
580	763428	3503	3578	3653	3727	3802	3877	3952	4027	4101	75
581	4176	4251	4326	4400	4475	4550	4624	4699	4774	4848	75
582	4923	4998	5072	5147	5221	5296	5370	5445	5520	5594	75
583	5669	5743	5818	5892	5966	6041	6115	6190	6264	6338	74
584	6413	6487	6562	6636	6710	6785	6859	6933	7007	7082	74
585	767156	7230	7304	7379	7453	7527	7601	7675	7749	7823	74
586	7898	7972	8046	8120	8194	8268	8342	8416	8490	8564	74
587	8638	8712	8786	8860	8934	9008	9082	9156	9230	9303	74
588	9377	9451	9525	9599	9673	9746	9820	9894	9968	*0042	74
589	770115	0189	0263	0336	0410	0484	0557	0631	0705	0778	74
590	770852	0926	0999	1073	1146	1220	1293	1367	1440	1514	74
591	1587	1661	1734	1808	1881	1955	2028	2102	2175	2248	73
592	2322	2395	2468	2542	2615	2688	2762	2835	2908	2981	73
593	3055	3128	3201	3274	3348	3421	3494	3567	3640	3713	73
594	3786	3860	3933	4006	4079	4152	4225	4298	4371	4444	73
595	774517	4590	4663	4736	4809	4882	4955	5028	5100	5173	73
596	5246	5319	5392	5465	5538	5610	5683	5756	5829	5902	73
597	5974	6047	6120	6193	6265	6338	6411	6483	6556	6629	73
598	6701	6774	6846	6919	6992	7064	7137	7209	7282	7354	73
599	7427	7499	7572	7644	7717	7789	7862	7934	8006	8079	72

N.	Diff.	1	2	3	4	5	6	7	8	9	Diff.
PRO. PARTS	78	8	16	23	31	39	47	55	62	70	78
	77	8	15	23	31	39	46	54	62	69	77
	76	8	15	23	30	38	46	53	61	68	76
	75	8	15	23	30	38	45	53	60	68	75
	74	7	15	22	30	37	44	52	59	67	74
	73	7	15	22	29	37	44	51	58	66	73
	72	7	14	22	29	36	43	50	58	65	72
	Diff.	1	2	3	4	5	6	7	8	9	Diff.

N	0	1	2	3	4	5	6	7	8	9	Diff.
600	778151	8224	8296	8368	8441	8513	8585	8658	8730	8802	72
601	8874	8947	9019	9091	9163	9236	9308	9380	9452	9524	72
602	9596	9669	9741	9813	9885	9957	*0029	*0101	*0173	*0245	72
603	779317	0389	0461	0533	0605	0677	0749	0821	0893	0965	72
604	1037	1109	1181	1253	1324	1396	1468	1540	1612	1684	72
605	781755	1827	1899	1971	2042	2114	2186	2258	2329	2401	72
606	2473	2544	2616	2688	2759	2831	2902	2974	3046	3117	72
607	3189	3260	3332	3403	3475	3546	3618	3689	3761	3832	71
608	3904	3975	4046	4118	4189	4261	4332	4403	4475	4546	71
609	4617	4689	4760	4831	4902	4974	5045	5116	5187	5259	71
610	785330	5401	5472	5543	5615	5686	5757	5828	5899	5970	71
611	6041	6112	6183	6254	6325	6396	6467	6538	6609	6680	71
612	6751	6822	6893	6964	7035	7106	7177	7248	7319	7390	71
613	7460	7531	7602	7673	7744	7815	7885	7956	8027	8098	71
614	8168	8239	8310	8381	8451	8522	8593	8663	8734	8804	71
615	788875	8946	9016	9087	9157	9228	9299	9369	9440	9510	71
616	9581	9651	9722	9792	9863	9933	*0004	*0074	*0144	*0215	70
617	790285	0356	0426	0496	0567	0637	0707	0778	0848	0918	70
618	0988	1059	1129	1199	1269	1340	1410	1480	1550	1620	70
619	1691	1761	1831	1901	1971	2041	2111	2181	2252	2322	70
620	792392	2462	2532	2602	2672	2742	2812	2882	2952	3022	70
621	3092	3162	3231	3301	3371	3441	3511	3581	3651	3721	70
622	3790	3860	3930	4000	4070	4139	4209	4279	4349	4418	70
623	4488	4558	4627	4697	4767	4836	4906	4976	5045	5115	70
624	5185	5254	5324	5393	5463	5532	5602	5672	5741	5811	70
625	795880	5949	6019	6088	6158	6227	6297	6366	6436	6505	69
626	6574	6644	6713	6782	6852	6921	6990	7060	7129	7198	69
627	7268	7337	7406	7475	7545	7614	7683	7752	7821	7890	69
628	7960	8029	8098	8167	8236	8305	8374	8443	8513	8582	69
629	8651	8720	8789	8858	8927	8996	9065	9134	9203	9272	69
630	799341	9409	9478	9547	9616	9685	9754	9823	9892	9961	69
631	800029	0098	0167	0236	0305	0373	0442	0511	0580	0648	69
632	0717	0786	0854	0923	0992	1061	1129	1198	1266	1335	69
633	1404	1472	1541	1609	1678	1747	1815	1884	1952	2021	69
634	2089	2158	2226	2295	2363	2432	2500	2568	2637	2705	68
635	802774	2842	2910	2979	3047	3116	3184	3252	3321	3389	68
636	3457	3525	3594	3662	3730	3798	3867	3935	4003	4071	68
637	4139	4208	4276	4344	4412	4480	4548	4616	4685	4753	68
638	4821	4889	4957	5025	5093	5161	5229	5297	5365	5433	68
639	5501	5569	5637	5705	5773	5841	5908	5976	6044	6112	68
640	806180	6248	6316	6384	6451	6519	6587	6655	6723	6790	68
641	6858	6926	6994	7061	7129	7197	7264	7332	7400	7467	68
642	7535	7603	7670	7738	7806	7873	7941	8008	8076	8143	68
643	8211	8279	8346	8414	8481	8549	8616	8684	8751	8818	67
644	8886	8953	9021	9088	9156	9223	9290	9358	9425	9492	67
645	809560	9627	9694	9762	9829	9896	9964	*0031	*0098	*0165	67
646	810233	0300	0367	0434	0501	0569	0636	0703	0770	0837	67
647	0904	0971	1039	1106	1173	1240	1307	1374	1441	1508	67
648	1575	1642	1709	1776	1843	1910	1977	2044	2111	2178	67
649	2245	2312	2379	2445	2512	2579	2646	2713	2780	2847	67
N.	Diff.	1	2	3	4	5	6	7	8	9	Diff.
PRO. P'TS	73	7	15	22	29	37	44	51	58	66	73
	72	7	14	22	29	36	43	50	58	65	72
	71	7	14	21	28	36	43	50	57	64	71
	70	7	14	21	28	35	42	49	56	63	70
	69	7	14	21	28	35	41	48	55	62	69
	68	7	14	20	27	34	41	48	54	61	68
	Diff.	1	2	3	4	5	6	7	8	9	Diff.

N.	0	1	2	3	4	5	6	7	8	9	Diff
650	812913	2980	3047	3114	3181	3247	3314	3381	3448	3514	67
651	3581	3648	3714	3781	3848	3914	3981	4048	4114	4181	67
652	4248	4314	4381	4447	4514	4581	4647	4714	4780	4847	67
653	4913	4980	5046	5113	5179	5246	5312	5378	5445	5511	66
654	5578	5644	5711	5777	5843	5910	5976	6042	6109	6175	66
655	816241	6308	6374	6440	6506	6573	6639	6705	6771	6838	66
656	6904	6970	7036	7102	7169	7235	7301	7367	7433	7499	66
657	7565	7631	7698	7764	7830	7896	7962	8028	8094	8160	66
658	8226	8292	8358	8424	8490	8556	8622	8688	8754	8820	66
659	8885	8951	9017	9083	9149	9215	9281	9346	9412	9478	66
660	819544	9610	9676	9741	9807	9873	9939	*0004	*0070	*0136	66
661	820201	0267	0333	0399	0464	0530	0595	0661	0727	0792	66
662	0858	0924	0989	1055	1120	1186	1251	1317	1382	1448	66
663	1514	1579	1645	1710	1775	1841	1906	1972	2037	2103	65
664	2168	2233	2299	2364	2430	2495	2560	2626	2691	2756	65
665	822822	2887	2952	3018	3083	3148	3213	3279	3344	3409	65
666	3474	3539	3605	3670	3735	3800	3865	3930	3996	4061	65
667	4126	4191	4256	4321	4386	4451	4516	4581	4646	4711	65
668	4776	4841	4906	4971	5036	5101	5166	5231	5296	5361	65
669	5426	[illegible]	5556	5621	5686	5751	5815	5880	5945	6010	65
670	826075	6140	6204	6269	6334	6399	6464	6528	6593	6658	65
671	6723	6787	6852	6917	6981	7046	7111	7175	7240	7305	65
672	7369	7434	7499	7563	7628	7692	7757	7821	7886	7951	65
673	8015	8080	8144	8209	8273	8338	8402	8467	8531	8595	64
674	8660	8724	8789	8853	8918	8982	9046	9111	9175	9239	64
675	829304	9368	9432	9497	9561	9625	9690	9754	9818	9882	64
676	9947	*0011	*0075	*0139	*0204	*0268	*0332	*0396	*0460	*0525	64
677	830589	0653	0717	0781	0845	0909	0973	1037	1102	1166	64
678	1230	1294	1358	1422	1486	1550	1614	1678	1742	1806	64
679	1870	1934	1998	2062	2126	2189	2253	2317	2381	[illegible]	64
680	832509	2573	2637	2700	2764	2828	2892	2956	3020	3083	64
681	3147	3211	3275	3338	3402	3466	3530	3593	3657	3721	64
682	3784	3848	3912	3975	4039	4103	4166	4230	4294	4357	64
683	4421	4484	4548	4611	4675	4739	4802	4866	4929	4993	64
684	5056	5120	5183	5247	5310	5373	5437	5500	5564	5627	63
685	835691	5754	5817	5881	5944	6007	6071	6134	6197	6261	63
686	6324	6387	6451	6514	6577	6641	6704	6767	6830	6894	63
687	6957	7020	7083	7146	7210	7273	7336	7399	7462	7525	63
688	7588	7652	7715	7778	7841	7904	7967	8030	8093	8156	63
689	8219	8282	8345	8408	8471	8534	8597	8660	8723	8786	63
690	838849	8912	8975	9038	9101	9164	9227	9289	9352	9415	63
691	9478	9541	9604	9667	9729	9792	9855	9918	9981	*0043	63
692	840106	0169	0232	0294	0357	0420	0482	0545	0608	0671	63
693	0733	0796	0859	0921	0984	1046	1109	1172	1234	1297	63
694	1359	1422	1485	1547	1610	1672	1735	1797	1860	1922	63
695	841985	2047	2110	2172	2235	2297	2360	2422	2484	2547	62
696	2609	2672	2734	2796	2859	2921	2983	3046	3108	3170	62
697	3233	3295	3357	3420	3482	3544	3606	3669	3731	3793	62
698	3855	3918	3980	4042	4104	4166	4229	4291	4353	4415	62
699	4477	4539	4601	4664	4726	4788	4850	4912	4974	5036	62

N.	Diff.	1	2	3	4	5	6	7	8	9	Diff.
PRO. PTS.	67	7	13	20	27	34	40	47	54	60	67
	66	7	13	20	26	33	40	46	53	59	66
	65	7	13	20	26	33	39	46	52	59	65
	64	6	13	19	26	32	38	45	51	58	64
	63	6	13	19	25	32	38	44	50	57	63
	62	6	12	19	25	31	37	43	50	56	62
	Diff.	1	2	3	4	5	6	7	8	9	Diff.

N.	0	1	2	3	4	5	6	7	8	9	Diff.
700	845098	5160	5222	5284	5346	5408	5470	5532	5594	5656	62
701	5718	5780	5842	5904	5966	6028	6090	6151	6213	6275	62
702	6337	6399	6461	6523	6585	6646	6708	6770	6832	6894	62
703	6955	7017	7079	7141	7202	7264	7326	7388	7449	7511	62
704	7573	7634	7696	7758	7819	7881	7943	8004	8066	8128	62
705	848189	8251	8312	8374	8435	8497	8559	8620	8682	8743	62
706	8805	8866	8928	8989	9051	9112	9174	9235	9297	9358	61
707	9419	9481	9542	9604	9665	9726	9788	9849	9911	9972	61
708	850033	0095	0156	0217	0279	0340	0401	0462	0524	0585	61
709	0646	0707	0769	0830	0891	0952	1014	1075	1136	1197	61
710	851258	1320	1381	1442	1503	1564	1625	1686	1747	1809	61
711	1870	1931	1992	2053	2114	2175	2236	2297	2358	2419	61
712	2480	2541	2602	2663	2724	2785	2846	2907	2968	3029	61
713	3090	3150	3211	3272	3333	3394	3455	3516	3577	3637	61
714	3698	3759	3820	3881	3941	4002	4063	4124	4185	4245	61
715	854306	4367	4428	4488	4549	4610	4670	4731	4792	4852	61
716	4913	4974	5034	5095	5156	5216	5277	5337	5398	5459	61
717	5519	5580	5640	5701	5761	5822	5882	5943	6003	6064	61
718	6124	6185	6245	6306	6366	6427	6487	6548	6608	6668	60
719	6729	6789	6850	6910	6970	7031	7091	7152	7212	7272	60
720	857332	7393	7453	7513	7574	7634	7694	7755	7815	7875	60
721	7935	7995	8056	8116	8176	8236	8297	8357	8417	8477	60
722	8537	8597	8657	8718	8778	8838	8898	8958	9018	9078	60
723	9138	9198	9258	9318	9379	9439	9499	9559	9619	9679	60
724	9739	9799	9859	9918	9978	*0038	*0098	*0158	*0218	*0278	60
725	860338	0398	0458	0518	0578	0637	0697	0757	0817	0877	60
726	0937	0996	1056	1116	1176	1236	1295	1355	1415	1475	60
727	1534	1594	1654	1714	1773	1833	1893	1952	2012	2072	60
728	2131	2191	2251	2310	2370	2430	2489	2549	2608	2668	60
729	2728	2787	2847	2906	2966	3025	3085	3144	3204	3263	60
730	863323	3382	3442	3501	3561	3620	3680	3739	3799	3858	59
731	3917	3977	4036	4096	4155	4214	4274	4333	4392	4452	59
732	4511	4570	4630	4689	4748	4808	4867	4926	4985	5045	59
733	5104	5163	5222	5282	5341	5400	5459	5519	5578	5637	59
734	5696	5755	5814	5874	5933	5992	6051	6110	6169	6228	59
735	866287	6346	6405	6465	6524	6583	6642	6701	6760	6819	59
736	6878	6937	6996	7055	7114	7173	7232	7291	7350	7409	59
737	7467	7526	7585	7644	7703	7762	7821	7880	7939	7998	59
738	8056	8115	8174	8233	8292	8350	8409	8468	8527	8586	59
739	8644	8703	8762	8821	8879	8938	8997	9056	9114	9173	59
740	869232	9290	9349	9408	9466	9525	9584	9642	9701	9760	59
741	9818	9877	9935	9994	*0053	*0111	*0170	*0228	*0287	*0345	59
742	870404	0462	0521	0579	0638	0696	0755	0813	0872	0930	59
743	0989	1047	1106	1164	1223	1281	1339	1398	1456	1515	58
744	1573	1631	1690	1748	1806	1865	1923	1981	2040	2098	58
745	872156	2215	2273	2331	2389	2448	2506	2564	2622	2681	58
746	2739	2797	2855	2913	2972	3030	3088	3146	3204	3262	58
747	3321	3379	3437	3495	3553	3611	3669	3727	3785	3844	58
748	3902	3960	4018	4076	4134	4192	4250	4308	4366	4424	58
749	4482	4540	4598	4656	4714	4772	4830	4888	4945	5003	58

N.	Diff.	1	2	3	4	5	6	7	8	9	Diff.
PRO. PTS.	62	6	12	19	25	31	37	43	50	56	62
	61	6	12	18	24	31	37	43	49	55	61
	60	6	12	18	24	30	36	42	48	54	60
	59	6	12	18	24	30	35	41	47	53	59
	58	6	12	17	23	29	35	41	46	52	58
	Diff.	1	2	3	4	5	6	7	8	9	Diff.

N.	0	1	2	3	4	5	6	7	8	9	Diff.
750	875061	5119	5177	5235	5293	5351	5409	5466	5524	5582	58
751	5640	5698	5756	5813	5871	5929	5987	6045	6102	6160	58
752	6218	6276	6333	6391	6449	6507	6564	6622	6680	6737	58
753	6795	6853	6910	6968	7026	7083	7141	7199	7256	7314	58
754	7371	7429	7487	7544	7602	7659	7717	7774	7832	7889	58
755	877947	8004	8062	8119	8177	8234	8292	8349	8407	8464	57
756	8522	8579	8637	8694	8752	8809	8866	8924	8981	9039	57
757	9096	9153	9211	9268	9325	9383	9440	9497	9555	9612	57
758	9669	9726	9784	9841	9898	9956	*0013	*0070	*0127	*0185	57
759	880242	0299	0356	0413	0471	0528	0585	0642	0699	0756	57
760	880814	0871	0928	0985	1042	1099	1156	1213	1271	1328	57
761	1385	1442	1499	1556	1613	1670	1727	1784	1841	1898	57
762	1955	2012	2069	2126	2183	2240	2297	2354	2411	2468	57
763	2525	2581	2638	2695	2752	2809	2866	2923	2980	3037	57
764	3093	3150	3207	3264	3321	3377	3434	3491	3548	3605	57
765	883661	3718	3775	3832	3888	3945	4002	4059	4115	4172	57
766	4229	4285	4342	4399	4455	4512	4569	4625	4682	4739	57
767	4795	4852	4909	4965	5022	5078	5135	5192	5248	5305	57
768	5361	5418	5474	5531	5587	5644	5700	5757	5813	5870	57
769	5926	5983	6039	6096	6152	6209	6265	6321	6378	6434	56
770	886491	6547	6604	6660	6716	6773	6829	6885	6942	6998	56
771	7054	7111	7167	7223	7280	7336	7392	7449	7505	7561	56
772	7617	7674	7730	7786	7842	7898	7955	8011	8067	8123	56
773	8179	8236	8292	8348	8404	8460	8516	8573	8629	8685	56
774	8741	8797	8853	8909	8965	9021	9077	9134	9190	9246	56
775	889302	9358	9414	9470	9526	9582	9638	9694	9750	9806	56
776	9862	9918	9974	*0030	*0086	*0141	*0197	*0253	*0309	*0365	56
777	890421	0477	0533	0589	0645	0700	0756	0812	0868	0924	56
778	0980	1035	1091	1147	1203	1259	1314	1370	1426	1482	56
779	1537	1593	1649	1705	1760	1816	1872	1928	1983	2039	56
780	892095	2150	2206	2262	2317	2373	2429	2484	2540	2595	56
781	2651	2707	2762	2818	2873	2929	2985	3040	3096	3151	56
782	3207	3262	3318	3373	3429	3484	3540	3595	3651	3706	56
783	3762	3817	3873	3928	3984	4039	4094	4150	4205	4261	55
784	4316	4371	4427	4482	4538	4593	4648	4704	4759	4814	55
785	894870	4925	4980	5036	5091	5146	5201	5257	5312	5367	55
786	5423	5478	5533	5588	5644	5699	5754	5809	5864	5920	55
787	5975	6030	6085	6140	6195	6251	6306	6361	6416	6471	55
788	6526	6581	6636	6692	6747	6802	6857	6912	6967	7022	55
789	7077	7132	7187	7242	7297	7352	7407	7462	7517	7572	55
790	897627	7682	7737	7792	7847	7902	7957	8012	8067	8122	55
791	8176	8231	8286	8341	8396	8451	8506	8561	8615	8670	55
792	8725	8780	8835	8890	8944	8999	9054	9109	9164	9218	55
793	9273	9328	9383	9437	9492	9547	9602	9656	9711	9766	55
794	9821	9875	9930	9985	*0039	*0094	*0149	*0203	*0258	*0312	55
795	900367	0422	0476	0531	0586	0640	0695	0749	0804	0859	55
796	0913	0968	1022	1077	1131	1186	1240	1295	1349	1404	55
797	1458	1513	1567	1622	1676	1731	1785	1840	1894	1948	54
798	2003	2057	2112	2166	2221	2275	2329	2384	2438	2492	54
799	2547	2601	2655	2710	2764	2818	2873	2927	2981	3036	54

N.	Diff.	1	2	3	4	5	6	7	8	9	Diff.
Pr. Pts.	57	6	11	17	23	29	34	40	46	51	57
	56	6	11	17	22	28	34	39	45	50	56
	55	6	11	17	22	28	33	39	44	50	55
	54	5	11	16	22	27	32	38	43	49	54
	Diff.	1	2	3	4	5	6	7	8	9	Diff.

N.	0	1	2	3	4	5	6	7	8	9	Diff.
800	903090	3144	3199	3253	3307	3361	3416	3470	3524	3578	54
801	3633	3687	3741	3795	3849	3904	3958	4012	4066	4120	54
802	4174	4229	4283	4337	4391	4445	4499	4553	4607	4661	54
803	4716	4770	4824	4878	4932	4986	5040	5094	5148	5202	54
804	5256	5310	5364	5418	5472	5526	5580	5634	5688	5742	54
805	905796	5850	5904	5958	6012	6066	6119	6173	6227	6281	54
806	6335	6389	6443	6497	6551	6604	6658	6712	6766	6820	54
807	6874	6927	6981	7035	7089	7143	7196	7250	7304	7358	54
808	7411	7465	7519	7573	7626	7680	7734	7787	7841	7895	54
809	7949	8002	8056	8110	8163	8217	8270	8324	8378	8431	54
810	908485	8539	8592	8646	8699	8753	8807	8860	8914	8967	54
811	9021	9074	9128	9181	9235	9289	9342	9396	9449	9503	54
812	9556	9610	9663	9716	9770	9823	9877	9930	9984	*0037	53
813	910091	0144	0197	0251	0304	0358	0411	0464	0518	0571	53
814	0624	0678	0731	0784	0838	0891	0944	0998	1051	1104	53
815	911158	1211	1264	1317	1371	1424	1477	1530	1584	1637	53
816	1690	1743	1797	1850	1903	1956	2009	2063	2116	2169	53
817	2222	2275	2328	2381	2435	2488	2541	2594	2647	2700	53
818	2753	2806	2859	2913	2966	3019	3072	3125	3178	3231	53
819	3284	3337	3390	3443	3496	3549	3602	3655	3708	3761	53
820	913814	3867	3920	3973	4026	4079	4132	4184	4237	4290	53
821	4343	4396	4449	4502	4555	4608	4660	4713	4766	4819	53
822	4872	4925	4977	5030	5083	5136	5189	5241	5294	5347	53
823	5400	5453	5505	5558	5611	5664	5716	5769	5822	5875	53
824	5927	5980	6033	6085	6138	6191	6243	6296	6349	6401	53
825	916454	6507	6559	6612	6664	6717	6770	6822	6875	6927	53
826	6980	7033	7085	7138	7190	7243	7295	7348	7400	7453	53
827	7506	7558	7611	7663	7716	7768	7820	7873	7925	7978	52
828	8030	8083	8135	8188	8240	8293	8345	8397	8450	8502	52
829	8555	8607	8659	8712	8764	8816	8869	8921	8973	9026	52
830	919078	9130	9183	9235	9287	9340	9392	9444	9496	9549	52
831	9601	9653	9706	9758	9810	9862	9914	9967	*0019	*0071	52
832	920123	0176	0228	0280	0332	0384	0436	0489	0541	0593	52
833	0645	0697	0749	0801	0853	0906	0958	1010	1062	1114	52
834	1166	1218	1270	1322	1374	1426	1478	1530	1582	1634	52
835	921686	1738	1790	1842	1894	1946	1998	2050	2102	2154	52
836	2206	2258	2310	2362	2414	2466	2518	2570	2622	2674	52
837	2725	2777	2829	2881	2933	2985	3037	3089	3140	3192	52
838	3244	3296	3348	3399	3451	3503	3555	3607	3658	3710	52
839	3762	3814	3865	3917	3969	4021	4072	4124	4176	4228	52
840	924279	4331	4383	4434	4486	4538	4589	4641	4693	4744	52
841	4796	4848	4899	4952	5004	5054	5106	5157	5209	5261	52
842	5312	5364	5415	5467	5518	5570	5621	5673	5725	5776	52
843	5828	5879	5931	5982	6034	6085	6137	6188	6240	6291	51
844	6342	6394	6445	6497	6548	6600	6651	6702	6754	6805	51
845	926857	6908	6959	7011	7062	7114	7165	7216	7268	7319	51
846	7370	7422	7473	7524	7576	7627	7678	7730	7781	7832	51
847	7883	7935	7986	8037	8088	8140	8191	8242	8293	8345	51
848	8396	8447	8498	8549	8601	8652	8703	8754	8805	8857	51
849	8908	8959	9010	9061	9112	9163	9215	9266	9317	9368	51

N.	Diff.	1	2	3	4	5	6	7	8	9	Diff.
PR. PTS.	55	6	11	17	22	28	33	39	44	50	55
	54	5	11	16	22	27	32	38	43	49	54
	53	5	11	16	21	27	32	37	42	48	53
	52	5	10	16	21	26	31	36	42	47	52
	Diff.	1	2	3	4	5	6	7	8	9	Diff.

N.	0	1	2	3	4	5	6	7	8	9	Dif.
850	929419	9470	9521	9572	9623	9674	9725	9776	9827	9879	51
851	9930	9981	*0032	*0083	*0134	*0185	*0236	*0287	*0338	*0389	51
852	930440	0491	0542	0592	0643	0694	0745	0796	0847	0898	51
853	0949	1000	1051	1102	1153	1204	1254	1305	1356	1407	51
854	1458	1509	1560	1610	1661	1712	1763	1814	1865	1915	51
855	931966	2017	2068	2118	2169	2220	2271	2322	2372	2423	51
856	2474	2524	2575	2626	2677	2727	2778	2829	2879	2930	51
857	2981	3031	3082	3133	3183	3234	3285	3335	3386	3437	51
858	3487	3538	3589	3639	3690	3740	3791	3841	3892	3943	51
859	3993	4044	4094	4145	4195	4246	4296	4347	4397	4448	51
860	934498	4549	4599	4650	4700	4751	4801	4852	4902	4953	50
861	5003	5054	5104	5154	5205	5255	5306	5356	5406	5457	50
862	5507	5558	5608	5658	5709	5759	5809	5860	5910	5960	50
863	6011	6061	6111	6162	6212	6262	6313	6363	6413	6463	50
864	6514	6564	6614	6665	6715	6765	6815	6865	6916	6966	50
865	937016	7066	7117	7167	7217	7267	7317	7367	7418	7468	50
866	7518	7568	7618	7668	7718	7769	7819	7869	7919	7969	50
867	8019	8069	8119	8169	8219	8269	8320	8370	8420	8470	50
868	8520	8570	8620	8670	8720	8770	8820	8870	8920	8970	50
869	9020	9070	9120	9170	9220	9270	9320	9369	9419	9469	50
870	939519	9569	9619	9669	9719	9769	9819	9869	9918	9968	50
871	940018	0068	0118	0168	0218	0267	0317	0367	0417	0467	50
872	0516	0566	0616	0666	0716	0765	0815	0865	0915	0964	50
873	1014	1064	1114	1163	1213	1263	1313	1362	1412	1462	50
874	1511	1561	1611	1660	1710	1760	1809	1859	1909	1958	50
875	942008	2058	2107	2157	2207	2256	2306	2355	2405	2455	50
876	2504	2554	2603	2653	2702	2752	2801	2851	2901	2950	50
877	3000	3049	3099	3148	3198	3247	3297	3346	3396	3445	49
878	3495	3544	3593	3643	3692	3742	3791	3841	3890	3939	49
879	3989	4038	4088	4137	4186	4236	4285	4335	4384	4433	49
880	944483	4532	4581	4631	4680	4729	4779	4828	4877	4927	49
881	4976	5025	5074	5124	5173	5222	5272	5321	5370	5419	49
882	5469	5518	5567	5616	5665	5715	5764	5813	5862	5912	49
883	5961	6010	6059	6108	6157	6207	6256	6305	6354	6403	49
884	6452	6501	6551	6600	6649	6698	6747	6796	6845	6894	49
885	946943	6992	7041	7090	7140	7189	7238	7287	7336	7385	49
886	7434	7483	7532	7581	7630	7679	7728	7777	7826	7875	49
887	7924	7973	8022	8070	8119	8168	8217	8266	8315	8364	49
888	8413	8462	8511	8560	8609	8657	8706	8755	8804	8853	49
889	8902	8951	8999	9048	9097	9146	9195	9244	9292	9341	49
890	949390	9439	9488	9536	9585	9634	9683	9731	9780	9829	49
891	9878	9926	9975	*0024	*0073	*0121	*0170	*0219	*0267	*0316	49
892	950365	0414	0462	0511	0560	0608	0657	0706	0754	0803	49
893	0851	0900	0949	0997	1046	1095	1143	1192	1240	1289	49
894	1338	1386	1435	1483	1532	1580	1629	1677	1726	1775	49
895	951823	1872	1920	1969	2017	2066	2114	2163	2211	2260	49
896	2308	2356	2405	2453	2502	2550	2599	2647	2696	2744	48
897	2792	2841	2889	2938	2986	3034	3083	3131	3180	3228	48
898	3276	3325	3373	3421	3470	3518	3566	3615	3663	3711	48
899	3760	3808	3856	3905	3953	4001	4049	4098	4146	4194	48

N.	Dif.	1	2	3	4	5	6	7	8	9	Dif.
Pr. Pts.	51	5	10	15	20	26	31	36	41	46	51
	50	5	10	15	20	25	30	35	40	45	50
	49	5	10	15	20	25	29	34	39	44	49
	48	5	10	14	19	24	29	34	38	43	48
	Dif.	1	2	3	4	5	6	7	8	9	Dif.

N.	0	1	2	3	4	5	6	7	8	9	Diff.
900	954243	4291	4339	4387	4435	4484	4532	4580	4628	4677	48
901	4725	4773	4821	4869	4918	4966	5014	5062	5110	5158	48
902	5207	5255	5303	5351	5399	5447	5495	5543	5592	5640	48
903	5688	5736	5784	5832	5880	5928	5976	6024	6072	6120	48
904	6168	6216	6265	6313	6361	6409	6457	6505	6553	6601	48
905	956649	6697	6745	6793	6840	6888	6936	6984	7032	7080	48
906	7128	7176	7224	7272	7320	7368	7416	7464	7512	7559	48
907	7607	7655	7703	7751	7799	7847	7894	7942	7990	8038	48
908	8086	8134	8181	8229	8277	8325	8373	8421	8468	8516	48
909	8564	8612	8659	8707	8755	8803	8850	8898	8946	8994	48
910	959041	9089	9137	9185	9232	9280	9328	9375	9423	9471	48
911	9518	9566	9614	9661	9709	9757	9804	9852	9900	9947	48
912	9995	*0042	*0090	*0138	*0185	*0233	*0280	*0328	*0376	*0423	48
913	960471	0518	0566	0613	0661	0709	0756	0804	0851	0899	48
914	0946	0994	1041	1089	1136	1184	1231	1279	1326	1374	48
915	961421	1469	1516	1563	1611	1658	1706	1753	1801	1848	47
916	1895	1943	1990	2038	2085	2132	2180	2227	2275	2322	47
917	2369	2417	2464	2511	2559	2606	2653	2701	2748	2795	47
918	2843	2890	2937	2985	3032	3079	3126	3174	3221	3268	47
919	3316	3363	3410	3457	3504	3552	3599	3646	3693	3741	47
920	963788	3835	3882	3929	3977	4024	4071	4118	4165	4212	47
921	4260	4307	4354	4401	4448	4495	4542	4590	4637	4684	47
922	4731	4778	4825	4872	4919	4966	5013	5061	5108	5155	47
923	5202	5249	5296	5343	5390	5437	5484	5531	5578	5625	47
924	5672	5719	5766	5813	5860	5907	5954	6001	6048	6095	47
925	966142	6189	6236	6283	6329	6376	6423	6470	6517	6564	47
926	6611	6658	6705	6752	6799	6845	6892	6939	6986	7033	47
927	7080	7127	7173	7220	7267	7314	7361	7408	7454	7501	47
928	7548	7595	7642	7688	7735	7782	7829	7875	7922	7969	47
929	8016	8062	8109	8156	8203	8249	8296	8343	8390	8436	47
930	968483	8530	8576	8623	8670	8716	8763	8810	8856	8903	47
931	8950	8996	9043	9090	9136	9183	9229	9276	9323	9369	47
932	9416	9463	9509	9556	9602	9649	9695	9742	9789	9835	47
933	9882	9928	9975	*0021	*0068	*0114	*0161	*0207	*0254	*0300	47
934	970347	0393	0440	0486	0533	0579	0626	0672	0719	0765	46
935	970812	0858	0904	0951	0997	1044	1090	1137	1183	1229	46
936	1276	1322	1369	1415	1461	1508	1554	1601	1647	1693	46
937	1740	1786	1832	1879	1925	1971	2018	2064	2110	2157	46
938	2203	2249	2295	2342	2388	2434	2481	2527	2573	2619	46
939	2666	2712	2758	2804	2851	2897	2943	2989	3035	3082	46
940	973128	3174	3220	3266	3313	3359	3405	3451	3497	3543	46
941	3590	3636	3682	3728	3774	3820	3866	3913	3959	4005	46
942	4051	4097	4143	4189	4235	4281	4327	4374	4420	4466	46
943	4512	4558	4604	4650	4696	4742	4788	4834	4880	4926	46
944	4972	5018	5064	5110	5156	5202	5248	5294	5340	5386	46
945	975432	5478	5524	5570	5616	5662	5707	5753	5799	5845	46
946	5891	5937	5983	6029	6075	6121	6167	6212	6258	6304	46
947	6350	6396	6442	6488	6533	6579	6625	6671	6717	6763	46
948	6808	6854	6900	6946	6992	7037	7083	7129	7175	7220	46
949	7266	7312	7358	7403	7449	7495	7541	7586	7632	7678	46

N.	Diff.	1	2	3	4	5	6	7	8	9	Diff.
PR. PTS.	49	5	10	15	20	25	29	34	39	44	49
	48	5	10	14	19	24	29	34	38	43	48
	47	5	9	14	19	24	28	33	38	42	47
	46	5	9	14	18	23	28	32	37	41	46
	Diff.	1	2	3	4	5	6	7	8	9	Diff.

N.	0	1	2	3	4	5	6	7	8	9	Diff.
950	977724	7769	7815	7861	7906	7952	7998	8043	8089	8135	46
51	8181	8226	8272	8317	8363	8409	8454	8500	8546	8591	46
52	8637	8683	8728	8774	8819	8865	8911	8956	9002	9047	46
53	9093	9138	9184	9230	9275	9321	9366	9412	9457	9503	46
54	9548	9594	9639	9685	9730	9776	9821	9867	9912	9958	46
55	980003	0049	0094	0140	0185	0231	0276	0322	0367	0412	45
56	0458	0503	0549	0594	0640	0685	0730	0776	0821	0867	45
57	0912	0957	1003	1048	1093	1139	1184	1229	1275	1320	45
58	1366	1411	1456	1501	1547	1592	1637	1683	1728	1773	45
59	1819	1864	1909	1954	2000	2045	2090	2135	2181	2226	45
960	982271	2316	2362	2407	2452	2497	2543	2588	2633	2678	45
61	2723	2769	2814	2859	2904	2949	2994	3040	3085	3130	45
62	3175	3220	3265	3310	3356	3401	3446	3491	3536	3581	45
63	3626	3671	3716	3761	3807	3852	3897	3942	3987	4032	45
64	4077	4122	4167	4212	4257	4302	4347	4392	4437	4482	45
65	984527	4572	4617	4662	4707	4752	4797	4842	4887	4932	45
66	4977	5022	5067	5112	5157	5202	5247	5292	5337	5382	45
67	5426	5471	5516	5561	5606	5651	5696	5741	5786	5830	45
68	5875	5920	5965	6010	6055	6100	6144	6189	6234	6279	45
69	6324	6369	6413	6458	6503	6548	6593	6637	6682	6727	45
970	986772	6817	6861	6906	6951	6996	7040	7085	7130	7175	45
71	7219	7264	7309	7353	7398	7443	7488	7532	7577	7622	45
72	7666	7711	7756	7800	7845	7890	7934	7979	8024	8068	45
73	8113	8157	8202	8247	8291	8336	8381	8425	8470	8514	45
74	8559	8604	8648	8693	8737	8782	8826	8871	8916	8960	45
75	989005	9049	9094	9138	9183	9227	9272	9316	9361	9405	45
76	9450	9494	9539	9583	9628	9672	9717	9761	9806	9850	44
77	9895	9939	9983	*0028	*0072	*0117	*0161	*0206	*0250	*0294	44
78	990339	0383	0428	0472	0516	0561	0605	0650	0694	0738	44
79	0783	0827	0871	0916	0960	1004	1049	1093	1137	1182	44
980	991226	1270	1315	1359	1403	1448	1492	1536	1580	1625	44
81	1669	1713	1758	1802	1846	1890	1935	1979	2023	2067	44
82	2111	2156	2200	2244	2288	2333	2377	2421	2465	2509	44
83	2554	2598	2642	2686	2730	2774	2819	2863	2907	2951	44
84	2995	3039	3083	3127	3172	3216	3260	3304	3348	3392	44
85	993436	3480	3524	3568	3613	3657	3701	3745	3789	3833	44
86	3877	3921	3965	4009	4053	4097	4141	4185	4229	4273	44
87	4317	4361	4405	4449	4493	4537	4581	4625	4669	4713	44
88	4757	4801	4845	4889	4933	4977	5021	5065	5108	5152	44
89	5196	5240	5284	5328	5372	5416	5460	5504	5547	5591	44
990	995635	5679	5723	5767	5811	5854	5898	5942	5986	6030	44
91	6074	6117	6161	6205	6249	6293	6337	6380	6424	6468	44
92	6512	6555	6599	6643	6687	6731	6774	6818	6862	6906	44
93	6949	6993	7037	7080	7124	7168	7212	7255	7299	7343	44
94	7386	7430	7474	7517	7561	7605	7648	7692	7736	7779	44
95	997823	7867	7910	7954	7998	8041	8085	8129	8172	8216	44
96	8259	8303	8347	8390	8434	8477	8521	8564	8608	8652	44
97	8695	8739	8782	8826	8869	8913	8956	9000	9043	9087	44
98	9131	9174	9218	9261	9305	9348	9392	9435	9479	9522	44
99	9565	9609	9652	9696	9739	9783	9826	9870	9913	9957	43

Diff.	1	2	3	4	5	6	7	8	9	Diff.
46	5	9	14	18	23	28	32	37	41	46
45	5	9	14	18	23	27	32	36	41	45
44	4	9	13	18	22	26	31	35	40	44
43	4	9	13	17	22	26	30	34	39	43
Diff.	1	2	3	4	5	6	7	8	9	Diff.

N.	0	1	2	3	4	5	6	7	8	9	Diff.
1000	000000	0043	0087	0130	0174	0217	0260	0304	0347	0391	43
1001	0434	0477	0521	0564	0608	0651	0694	0738	0781	0824	43
1002	0868	0911	0954	0998	1041	1084	1128	1171	1214	1258	43
1003	1301	1344	1388	1431	1474	1517	1561	1604	1647	1690	43
1004	1734	1777	1820	1863	1907	1950	1993	2036	2080	2123	43
1005	002166	2209	2252	2296	2339	2382	2425	2468	2512	2555	43
1006	2598	2641	2684	2727	2771	2814	2857	2900	2943	2986	43
1007	3029	3073	3116	3159	3202	3245	3288	3331	3374	3417	43
1008	3461	3504	3547	3590	3633	3676	3719	3762	3805	3848	43
1009	3891	3934	3977	4020	4063	4106	4149	4192	4235	4278	43
1010	004321	4364	4407	4450	4493	4536	4579	4622	4665	4708	43
1011	4751	4794	4837	4880	4923	4966	5009	5052	5095	5138	43
1012	5181	5223	5266	5309	5352	5395	5438	5481	5524	5567	43
1013	5609	5652	5695	5738	5781	5824	5867	5909	5952	5995	43
1014	6038	6081	6124	6166	6209	6252	6295	6338	6380	6423	43
1015	006466	6509	6552	6594	6637	6680	6723	6765	6808	6851	43
1016	6894	6936	6979	7022	7065	7107	7150	7193	7236	7278	43
1017	7321	7364	7406	7449	7492	7534	7577	7620	7662	7705	43
1018	7748	7790	7833	7876	7918	7961	8004	8046	8089	8132	43
1019	8174	8217	8259	8302	8345	8387	8430	8472	8515	8558	43
1020	008600	8643	8685	8728	8770	8813	8856	8898	8941	8983	43
1021	9026	9068	9111	9153	9196	9238	9281	9323	9366	9408	43
1022	9451	9493	9536	9578	9621	9663	9706	9748	9791	9833	42
1023	9876	9918	9961	*0003	*0045	*0088	*0130	*0173	*0215	*0258	42
1024	010300	0342	0385	0427	0470	0512	0554	0597	0639	0681	42
1025	010724	0766	0809	0851	0893	0936	0978	1020	1063	1105	42
1026	1147	1190	1232	1274	1317	1359	1401	1444	1486	1528	42
1027	1570	1613	1655	1697	1740	1782	1824	1866	1909	1951	42
1028	1993	2035	2078	2120	2162	2204	2247	2289	2331	2373	42
1029	2415	2458	2500	2542	2584	2626	2669	2711	2753	2795	42
1030	012837	2879	2922	2964	3006	3048	3090	3132	3174	3217	42
1031	3259	3301	3343	3385	3427	3469	3511	3553	3596	3638	42
1032	3680	3722	3764	3806	3848	3890	3932	3974	4016	4058	42
1033	4100	4142	4184	4226	4268	4310	4353	4395	4437	4479	42
1034	4521	4563	4605	4647	4689	4730	4772	4814	4856	4898	42
1035	014940	4982	[illegible]	5066	5108	5150	5192	5234	5276	5318	42
1036	5360	5402	[illegible]	5485	5527	5569	5611	5653	5695	5737	42
1037	5779	5821	[illegible]	5904	5946	5988	6030	6072	6114	6156	42
1038	6197	6239	6281	6323	6365	6407	6448	6490	6532	6574	42
1039	6616	6657	6699	6741	6783	6824	6866	6908	6950	6992	42
1040	017033	7075	7117	7159	7200	7242	7284	7326	7367	7409	42
1041	7451	7492	7534	7576	7618	7659	7701	7743	7784	7826	42
1042	7868	7909	7951	7993	8034	8076	8118	8159	8201	8243	42
1043	8284	8326	8368	8409	8451	8492	8534	8576	8617	8659	42
1044	8700	8742	8784	8825	8867	8908	8950	8992	9033	9075	42
1045	019116	9158	9199	9241	9282	9324	9366	9407	9449	9490	42
1046	9532	9573	9615	9656	9698	9739	9781	9822	9864	9905	42
1047	9947	9988	*0030	*0071	*0113	*0154	*0195	*0237	*0278	*0320	41
1048	020361	0403	0444	0486	0527	0568	0610	0651	0693	0734	41
1049	0775	0817	0858	0900	0941	0982	1024	1065	1107	1148	41
1050	021189	1231	1272	1313	1355	1396	1437	1479	1520	1561	41

N.	Diff.	1	2	3	4	5	6	7	8	9	Diff.
PR. PTS.	44	4	9	13	18	22	26	31	35	40	44
	43	4	9	13	17	22	26	30	34	39	43
	42	4	8	13	17	21	25	29	34	38	42
	41	4	8	12	16	21	25	29	33	37	41
	Diff.	1	2	3	4	5	6	7	8	9	Diff.

TABLE 75

Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
— ∞		10.000000		— ∞		— ∞	60
6.463726		.000000		6.463726		3.536274	59
.764756	5017.17	.000000	.00	.764756	5017.17	.235244	58
.940847	2934.85	.000000	.00	.940847	2934.85	.059153	57
7.065786	2082.32	.000000	.00	7.065786	2082.32	2.934214	56
7.162696	1615.17	10.000000	.00	7.162696	1615.17	2.837304	55
.241877	1319.68	9.999999	.02	.241878	1319.70	.758122	54
.308824	1115.78	.999999	.00	.308825	1115.78	.691175	53
.366816	966.53	.999999	.00	.366817	966.53	.633183	52
.417968	852.53	.999999	.00	.417970	852.55	.582030	51
7.463726	762.63	9.999998	.02	7.463727	762.62	2.536273	50
.505118	689.87	.999998	.00	.505120	689.88	.494880	49
.542906	629.80	.999997	.02	.542909	629.82	.457091	48
.577668	579.37	.999997	.00	.577672	579.38	.422328	47
.609853	536.42	.999996	.02	.609857	536.42	.390143	46
7.639816	499.38	9.999996	.00	7.639820	499.38	2.360180	45
.667845	467.15	.999995	.02	.667849	467.15	.332151	44
.694173	438.80	.999995	.00	.694179	438.83	.305821	43
.718997	413.73	.999994	.02	.719003	413.73	.280997	42
.742478	391.35	.999993	.02	.742484	391.35	.257516	41
7.764754	371.27	9.999993	.00	7.764761	371.28	2.235239	40
.785943	353.15	.999992	.02	.785951	353.17	.214049	39
.806146	336.72	.999991	.02	.806155	336.73	.193845	38
.825451	321.75	.999990	.02	.825460	321.75	.174540	37
.843934	308.05	.999989	.02	.843944	308.07	.156056	36
7.861662	295.47	9.999989	.00	7.861674	295.50	2.138326	35
.878695	283.88	.999988	.02	.878708	283.90	.121292	34
.895085	273.17	.999987	.02	.895099	273.18	.104901	33
.910879	263.23	.999986	.02	.910894	263.25	.089106	32
.926119	254.00	.999985	.02	.926134	254.00	.073866	31
7.940842	245.38	9.999983	.03	7.940858	245.40	2.059142	30
.955082	237.33	.999982	.02	.955100	237.37	.044900	29
.968870	229.80	.999981	.02	.968889	229.82	.031111	28
.982233	222.72	.999980	.02	.982253	222.73	.017747	27
.995198	216.08	.999979	.02	.995219	216.10	.004781	26
8.007787	209.82	9.999977	.03	8.007809	209.83	1.992191	25
.020021	203.90	.999976	.02	.020044	203.92	.979956	24
.031919	198.30	.999975	.02	.031945	198.35	.968055	23
.043501	193.03	.999973	.03	.043527	193.03	.956473	22
.054781	188.00	.999972	.02	.054809	188.03	.945191	21
8.065776	183.25	9.999971	.02	8.065806	183.28	1.934194	20
.076500	178.73	.999969	.03	.076531	178.75	.923469	19
.086965	174.42	.999968	.02	.086997	174.43	.913003	18
.097183	170.30	.999966	.03	.097217	170.33	.902783	17
.107167	166.40	.999964	.03	.107203	166.43	.892797	16
8.116926	162.65	9.999963	.02	8.116963	162.67	1.883037	15
.126471	159.08	.999961	.03	.126510	159.12	.873490	14
.135810	155.65	.999959	.03	.135851	155.68	.864149	13
.144953	152.38	.999958	.02	.144996	152.42	.855004	12
.153907	149.23	.999956	.03	.153952	149.27	.846048	11
8.162681	146.23	9.999954	.03	8.162727	146.25	1.837273	10
.171280	143.32	.999952	.03	.171328	143.35	.828672	9
.179713	140.55	.999950	.03	.179763	140.58	.820237	8
.187985	137.87	.999948	.03	.188036	137.88	.811964	7
.196102	135.28	.999946	.03	.196156	135.33	.803844	6
8.204070	132.80	9.999944	.03	8.204126	132.83	1.795874	5
.211895	130.42	.999942	.03	.211953	130.45	.788047	4
.219581	128.10	.999940	.03	.219641	128.13	.780359	3
.227134	125.88	.999938	.03	.227195	125.90	.772805	2
.234557	123.72	.999936	.03	.234621	123.77	.765379	1
8.241855	121.63	9.999934	.03	8.241921	121.67	1.758079	0
Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M.

* From Allen's "Field and Office Tables." Copyright,

M.	Sin.	D. 1".	Cos.	D. 1".	Tan.	D. 1".	Cot.	
0	8.241855	119.63	9.999934	.03	8.241921	119.68	1.758079	
1	.249033	117.68	.999932	.05	.249102	117.72	.750898	
2	.256094	115.80	.999929	.03	.256165	115.83	.743835	
3	.263042	113.98	.999927	.03	.263115	114.02	.736885	
4	.269881	112.22	.999925	.05	.269956	112.25	.730044	
5	8.276614	110.48	9.999922	.03	8.276691	110.53	1.723309	
6	.283243	108.83	.999920	.03	.283323	108.88	.716677	
7	.289773	107.23	.999918	.05	.289856	107.27	.710144	
8	.296207	105.65	.999915	.03	.296292	105.70	.703708	
9	.302546	104.13	.999913	.05	.302634	104.17	.697366	
10	8.308794	102.67	9.999910	.05	8.308884	102.70	1.691116	
11	.314954	101.22	.999907	.03	.315046	101.27	.684954	
12	.321027	99.82	.999905	.05	.321122	99.87	.678878	
13	.327016	98.47	.999902	.05	.327114	98.52	.672886	
14	.332924	97.15	.999899	.03	.333025	97.18	.666975	
15	8.338753	95.85	9.999897	.05	8.338856	95.90	1.661144	
16	.344504	94.62	.999894	.05	.344610	94.65	.655390	
17	.350181	93.37	.999891	.05	.350289	93.43	.649711	
18	.355783	92.20	.999888	.05	.355895	92.25	.644105	
19	.361315	91.03	.999885	.05	.361430	91.08	.638570	
20	8.366777	89.90	9.999882	.05	8.366895	89.95	1.633105	
21	.372171	88.80	.999879	.05	.372292	88.83	.627708	
22	.377499	87.72	.999876	.05	.377622	87.78	.622378	
23	.382762	86.67	.999873	.05	.382889	86.72	.617111	
24	.387962	85.65	.999870	.05	.388092	85.70	.611908	
25	8.393101	84.63	9.999867	.05	8.393234	84.68	1.606766	
26	.398179	83.67	.999864	.05	.398315	83.72	.601685	
27	.403199	82.70	.999861	.05	.403338	82.77	.596662	
28	.408161	81.78	.999858	.07	.408304	81.82	.591696	
29	.413068	80.85	.999854	.05	.413213	80.92	.586787	
30	8.417919	79.97	9.999851	.05	8.418068	80.02	1.581932	
31	.422717	79.08	.999848	.07	.422869	79.15	.577131	
32	.427462	78.23	.999844	.05	.427618	78.28	.572382	
33	.432156	77.40	.999841	.05	.432315	77.45	.567685	
34	.436800	76.57	.999838	.07	.436962	76.63	.563038	
35	8.441394	75.78	9.999834	.05	8.441560	75.83	1.558440	
36	.445941	74.98	.999831	.07	.446110	75.05	.553890	
37	.450440	74.22	.999827	.05	.450613	74.28	.549387	
38	.454893	73.47	.999824	.07	.455070	73.52	.544930	
39	.459301	72.73	.999820	.07	.459481	72.80	.540519	
40	8.463665	72.00	9.999816	.05	8.463849	72.05	1.536151	
41	.467985	71.30	.999813	.07	.468172	71.37	.531828	
42	.472263	70.58	.999809	.07	.472454	70.65	.527546	
43	.476498	69.92	.999805	.07	.476693	69.98	.523307	
44	.480693	69.25	.999801	.07	.480892	69.30	.519108	
45	8.484848	68.58	9.999797	.05	8.485050	68.67	1.514950	
46	.488963	67.95	.999794	.07	.489170	68.00	.510830	
47	.493040	67.30	.999790	.07	.493250	67.38	.506750	
48	.497078	66.70	.999786	.07	.497293	66.75	.502707	
49	.501080	66.08	.999782	.07	.501298	66.15	.498702	
50	8.505045	65.48	9.999778	.07	8.505267	65.55	1.494733	
51	.508974	64.88	.999774	.08	.509200	64.97	.490800	
52	.512867	64.32	.999769	.07	.513098	64.38	.486902	
53	.516726	63.75	.999765	.07	.516961	63.82	.483039	
54	.520551	63.20	.999761	.07	.520790	63.27	.479210	
55	8.524343	62.65	9.999757	.07	8.524586	62.72	1.475414	
56	.528102	62.10	.999753	.08	.528349	62.18	.471651	
57	.531828	61.58	.999748	.07	.532080	61.65	.467920	
58	.535523	61.05	.999744	.07	.535779	61.13	.464221	
59	.539186	60.55	.999740	.08	.539447	60.62	.460553	
60	8.542819		9.999735		8.543084		1.456916	
	Cos.	D. 1".	Sin.	D. 1".	Cot.	D. 1".	Tan.	M.

M.	Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
0	8.542819	60.05	9.999735	.07	8.543084	60.12	1.456916	60
1	.546422	59.55	.999731	.08	.546691	59.62	.453309	59
2	.549995	59.07	.999726	.07	.550268	59.15	.449732	58
3	.553539	58.58	.999722	.08	.553817	58.65	.446183	57
4	.557054	58.10	.999717	.07	.557336	58.20	.442664	56
5	8.560540	57.65	9.999713	.08	8.560828	57.72	1.439172	55
6	.563999	57.20	.999708	.07	.564291	57.27	.435709	54
7	.567431	56.75	.999704	.08	.567727	56.83	.432273	53
8	.570836	56.30	.999699	.08	.571137	56.38	.428863	52
9	.574214	55.87	.999694	.08	.574520	55.95	.425480	51
10	8.577566	55.43	9.999689	.07	8.577877	55.52	1.422123	50
11	.580892	55.02	.999685	.08	.581208	55.10	.418792	49
12	.584193	54.60	.999680	.08	.584514	54.68	.415486	48
13	.587469	54.20	.999675	.08	.587795	54.27	.412205	47
14	.590721	53.78	.999670	.08	.591051	53.87	.408949	46
15	8.593948	53.40	9.999665	.08	8.594283	53.48	1.405717	45
16	.597152	53.00	.999660	.08	.597492	53.08	.402508	44
17	.600332	52.62	.999655	.08	.600677	52.70	.399323	43
18	.603489	52.23	.999650	.08	.603839	52.32	.396161	42
19	.606623	51.85	.999645	.08	.606978	51.93	.393022	41
20	8.609734	51.48	9.999640	.08	8.610094	51.58	1.389906	40
21	.612823	51.13	.999635	.10	.613189	51.22	.386811	39
22	.615891	50.77	.999629	.08	.616262	50.85	.383738	38
23	.618937	50.42	.999624	.08	.619313	50.50	.380687	37
24	.621962	50.05	.999619	.08	.622343	50.15	.377657	36
25	8.624965	49.72	9.999614	.10	8.625352	49.80	1.374648	35
26	.627948	49.38	.999608	.08	.628340	49.47	.371660	34
27	.630911	49.05	.999603	.10	.631308	49.13	.368692	33
28	.633854	48.70	.999597	.08	.634256	48.80	.365744	32
29	.636776	48.40	.999592	.10	.637184	48.48	.362816	31
30	8.639680	48.05	9.999586	.08	8.640093	48.15	1.359907	30
31	.642563	47.75	.999581	.10	.642982	47.85	.357018	29
32	.645428	47.43	.999575	.08	.645853	47.52	.354147	28
33	.648274	47.13	.999570	.10	.648704	47.22	.351296	27
34	.651102	46.82	.999564	.10	.651537	46.92	.348463	26
35	8.653911	46.52	9.999558	.08	8.654352	46.62	1.345648	25
36	.656702	46.22	.999553	.10	.657149	46.32	.342851	24
37	.659475	45.92	.999547	.10	.659928	46.02	.340072	23
38	.662230	45.63	.999541	.10	.662689	45.73	.337311	22
39	.664968	45.35	.999535	.10	.665433	45.45	.334567	21
40	8.667689	45.07	9.999529	.08	8.668160	45.17	1.331840	20
41	.670393	44.78	.999524	.10	.670870	44.88	.329130	19
42	.673080	44.52	.999518	.10	.673563	44.60	.326437	18
43	.675751	44.23	.999512	.10	.676239	44.35	.323761	17
44	.678405	43.97	.999506	.10	.678900	44.07	.321100	16
45	8.681043	43.70	9.999500	.12	8.681544	43.80	1.318456	15
46	.683665	43.45	.999493	.10	.684172	43.53	.315828	14
47	.686272	43.18	.999487	.10	.686784	43.28	.313216	13
48	.688863	42.92	.999481	.10	.689381	43.03	.310619	12
49	.691438	42.67	.999475	.10	.691963	42.77	.308037	11
50	8.693998	42.42	9.999469	.10	8.694529	42.53	1.305471	10
51	.696543	42.17	.999463	.12	.697081	42.27	.302919	9
52	.699073	41.93	.999456	.10	.699617	42.03	.300383	8
53	.701589	41.68	.999450	.12	.702139	41.78	.297861	7
54	.704090	41.45	.999443	.10	.704646	41.57	.295354	6
55	8.706577	41.20	9.999437	.10	8.707140	41.30	1.292860	5
56	.709049	40.97	.999431	.12	.709618	41.08	.290382	4
57	.711507	40.75	.999424	.10	.712083	40.85	.287917	3
58	.713952	40.52	.999418	.12	.714534	40.63	.285466	2
59	.716383	40.28	.999411	.12	.716972	40.40	.283028	1
60	8.718800		9.999404		8.719396		1.280604	0
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M.

M.	Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
0	8.718800	40.07	9.999404	.10	8.719396	40.17	1.280604	60
1	.721204	39.85	.999398	.12	.721806	39.97	.278194	59
2	.723595	39.62	.999391	.12	.724204	39.73	.275796	58
3	.725972	39.42	.999384	.10	.726588	39.52	.273412	57
4	.728337	39.18	.999378	.12	.728959	39.30	.271041	56
5	8.730688	38.98	9.999371	.12	8.731317	39.10	1.268683	55
6	.733027	38.78	.999364	.12	.733663	38.88	.266337	54
7	.735354	38.55	.999357	.12	.735996	38.68	.264004	53
8	.737667	38.37	.999350	.12	.738317	38.48	.261683	52
9	.739969	38.17	.999343	.12	.740626	38.27	.259374	51
10	8.742259	37.95	9.999336	.12	8.742922	38.08	1.257078	50
11	.744536	37.77	.999329	.12	.745207	37.87	.254793	49
12	.746802	37.55	.999322	.12	.747479	37.68	.252521	48
13	.749055	37.37	.999315	.12	.749740	37.48	.250260	47
14	.751297	37.18	.999308	.12	.751989	37.30	.248011	46
15	8.753528	36.98	9.999301	.12	8.754227	37.10	1.245773	45
16	.755747	36.80	.999294	.12	.756453	36.92	.243547	44
17	.757955	36.60	.999287	.13	.758668	36.73	.241332	43
18	.760151	36.43	.999279	.12	.760872	36.55	.239128	42
19	.762337	36.23	.999272	.12	.763065	36.35	.236935	41
20	8.764511	36.07	9.999265	.13	8.765246	36.18	1.234754	40
21	.766675	35.88	.999257	.12	.767417	36.02	.232583	39
22	.768828	35.70	.999250	.13	.769578	35.82	.230422	38
23	.770970	35.52	.999242	.12	.771727	35.65	.228273	37
24	.773101	35.37	.999235	.13	.773866	35.48	.226134	36
25	8.775223	35.17	9.999227	.12	8.775995	35.32	1.224005	35
26	.777333	35.02	.999220	.13	.778114	35.13	.221886	34
27	.779434	34.83	.999212	.12	.780222	34.97	.219778	33
28	.781524	34.68	.999205	.13	.782320	34.80	.217680	32
29	.783605	34.50	.999197	.13	.784408	34.63	.215592	31
30	8.785675	34.35	9.999189	.13	8.786486	34.47	1.213514	30
31	.787736	34.18	.999181	.12	.788554	34.32	.211446	29
32	.789787	34.02	.999174	.13	.790613	34.15	.209387	28
33	.791828	33.85	.999166	.13	.792662	33.98	.207338	27
34	.793859	33.70	.999158	.13	.794701	33.83	.205299	26
35	8.795881	33.55	9.999150	.13	8.796731	33.68	1.203269	25
36	.797894	33.38	.999142	.13	.798752	33.52	.201248	24
37	.799897	33.25	.999134	.13	.800763	33.37	.199237	23
38	.801892	33.07	.999126	.13	.802765	33.22	.197235	22
39	.803876	32.93	.999118	.13	.804758	33.07	.195242	21
40	8.805852	32.78	9.999110	.13	8.806742	32.92	1.193258	20
41	.807819	32.63	.999102	.13	.808717	32.77	.191283	19
42	.809777	32.48	.999094	.13	.810683	32.63	.189317	18
43	.811726	32.35	.999086	.15	.812641	32.47	.187359	17
44	.813667	32.20	.999077	.13	.814589	32.33	.185411	16
45	8.815599	32.05	9.999069	.13	8.816529	32.20	1.183471	15
46	.817522	31.90	.999061	.13	.818461	32.05	.181539	14
47	.819436	31.78	.999053	.15	.820384	31.90	.179616	13
48	.821343	31.62	.999044	.13	.822298	31.78	.177702	12
49	.823240	31.50	.999036	.15	.824205	31.63	.175795	11
50	8.825130	31.35	9.999027	.13	8.826103	31.48	1.173897	10
51	.827011	31.22	.999019	.15	.827992	31.37	.172008	9
52	.828884	31.08	.999010	.13	.829874	31.23	.170126	8
53	.830749	30.97	.999002	.15	.831748	31.08	.168252	7
54	.832607	30.82	.998993	.15	.833613	30.97	.166387	6
55	8.834456	30.68	9.998984	.13	8.835471	30.83	1.164529	5
56	.836297	30.55	.998976	.15	.837321	30.70	.162679	4
57	.838130	30.43	.998967	.15	.839163	30.58	.160837	3
58	.839956	30.30	.998958	.13	.840998	30.45	.159002	2
59	.841774	30.18	.998950	.15	.842825	30.32	.157175	1
60	8.843585		9.998941		8.844644		1.155356	0
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M.

M.	Sin.	D. 1''.	Cos.	D. 1''.	Tan.	D. 1''.	Cot.	
0	8.843585	30.03	9.998941	.15	8.844644	30.18	1.155356	60
1	.845387	29.93	.998932	.15	.846455	30.08	.153545	59
2	.847183	29.80	.998923	.15	.848260	29.95	.151740	58
3	.848971	29.67	.998914	.15	.850057	29.82	.149943	57
4	.850751	29.57	.998905	.15	.851846	29.70	.148154	56
5	8.852525	29.43	9.998896	.15	8.853628	29.58	1.146372	55
6	.854291	29.30	.998887	.15	.855403	29.47	.144597	54
7	.856049	29.20	.998878	.15	.857171	29.35	.142829	53
8	.857801	29.08	.998869	.15	.858932	29.23	.141068	52
9	.859546	28.95	.998860	.15	.860686	29.12	.139314	51
10	8.861283	28.85	9.998851	.17	8.862433	29.00	1.137567	50
11	.863014	28.73	.998841	.15	.864173	28.88	.135827	49
12	.864738	28.62	.998832	.15	.865906	28.77	.134094	48
13	.866455	28.50	.998823	.17	.867632	28.65	.132368	47
14	.868165	28.38	.998813	.15	.869351	28.55	.130649	46
15	8.869868	28.28	9.998804	.15	8.871064	28.43	1.128936	45
16	.871565	28.17	.998795	.17	.872770	28.32	.127230	44
17	.873255	28.05	.998785	.15	.874469	28.22	.125531	43
18	.874938	27.95	.998776	.17	.876162	28.12	.123838	42
19	.876615	27.83	.998766	.15	.877849	28.00	.122151	41
20	8.878285	27.73	9.998757	.17	8.879529	27.88	1.120471	40
21	.879949	27.63	.998747	.15	.881202	27.78	.118798	39
22	.881607	27.52	.998738	.17	.882869	27.68	.117131	38
23	.883258	27.42	.998728	.17	.884530	27.58	.115470	37
24	.884903	27.32	.998718	.17	.886185	27.47	.113815	36
25	8.886542	27.20	9.998708	.15	8.887833	27.38	1.112167	35
26	.888174	27.12	.998699	.17	.889476	27.27	.110524	34
27	.889801	27.00	.998689	.17	.891112	27.17	.108888	33
28	.891421	26.90	.998679	.17	.892742	27.07	.107258	32
29	.893035	26.80	.998669	.17	.894366	26.97	.105634	31
30	8.894643	26.72	9.998659	.17	8.895984	26.87	1.104016	30
31	.896246	26.60	.998649	.17	.897596	26.78	.102404	29
32	.897842	26.50	.998639	.17	.899203	26.67	.100797	28
33	.899432	26.42	.998629	.17	.900803	26.58	.099197	27
34	.901017	26.32	.998619	.17	.902398	26.48	.097602	26
35	8.902596	26.22	9.998609	.17	8.903987	26.38	1.096013	25
36	.904169	26.12	.998599	.17	.905570	26.28	.094430	24
37	.905736	26.02	.998589	.18	.907147	26.20	.092853	23
38	.907297	25.93	.998578	.17	.908719	26.10	.091281	22
39	.908853	25.85	.998568	.17	.910285	26.02	.089715	21
40	8.910404	25.75	9.998558	.17	8.911846	25.92	1.088154	20
41	.911949	25.65	.998548	.18	.913401	25.83	.086599	19
42	.913488	25.57	.998537	.17	.914951	25.73	.085049	18
43	.915022	25.47	.998527	.18	.916495	25.65	.083505	17
44	.916550	25.38	.998516	.17	.918034	25.57	.081966	16
45	8.918073	25.30	9.998506	.18	8.919568	25.47	1.080432	15
46	.919591	25.20	.998495	.17	.921096	25.38	.078904	14
47	.921103	25.12	.998485	.18	.922619	25.28	.077381	13
48	.922610	25.03	.998474	.17	.924136	25.22	.075864	12
49	.924112	24.95	.998464	.18	.925649	25.12	.074351	11
50	8.925609	24.85	9.998453	.18	8.927156	25.03	1.072844	10
51	.927100	24.78	.998442	.18	.928658	24.95	.071342	9
52	.928587	24.68	.998431	.17	.930155	24.87	.069845	8
53	.930068	24.60	.998421	.18	.931647	24.78	.068353	7
54	.931544	24.52	.998410	.18	.933134	24.70	.066866	6
55	8.933015	24.43	9.998399	.18	8.934616	24.62	1.065384	5
56	.934481	24.35	.998388	.18	.936093	24.53	.063907	4
57	.935942	24.27	.998377	.18	.937565	24.45	.062435	3
58	.937398	24.20	.998366	.18	.939032	24.37	.060968	2
59	.938850	24.10	.998355	.18	.940494	24.30	.059506	1
60	8.940296		9.998344		8.941952		1.058048	0
	Cos.	D. 1''.	Sin.	D. 1''.	Cot.	D. 1''.	Tan.	M.

M.	Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
0	9.085894	17.13	9.996751	.27	9.089144	17.38	0.910856	60
1	.086922	17.08	.996735	.25	.090187	17.35	.909813	59
2	.087947	17.05	.996720	.27	.091228	17.30	.908772	58
3	.088970	17.00	.996704	.27	.092266	17.27	.907734	57
4	.089990	16.97	.996688	.25	.093302	17.23	.906698	56
5	9.091008	16.93	9.996673	.27	9.094336	17.18	0.905664	55
6	.092024	16.88	.996657	.27	.095367	17.13	.904633	54
7	.093037	16.83	.996641	.27	.096395	17.12	.903605	53
8	.094047	16.82	.996625	.25	.097422	17.07	.902578	52
9	.095056	16.77	.996610	.27	.098446	17.03	.901554	51
10	9.096062	16.72	9.996594	.27	9.099468	16.98	0.900532	50
11	.097065	16.68	.996578	.27	.100487	16.95	.899513	49
12	.098066	16.65	.996562	.27	.101504	16.92	.898496	48
13	.099065	16.62	.996546	.27	.102519	16.88	.897481	47
14	.100062	16.57	.996530	.27	.103532	16.83	.896468	46
15	9.101056	16.53	9.996514	.27	9.104542	16.80	0.895458	45
16	.102048	16.48	.996498	.27	.105550	16.77	.894450	44
17	.103037	16.47	.996482	.28	.106556	16.72	.893444	43
18	.104025	16.42	.996465	.27	.107559	16.68	.892441	42
19	.105010	16.37	.996449	.27	.108560	16.65	.891440	41
20	9.105992	16.35	9.996433	.27	9.109559	16.62	0.890441	40
21	.106973	16.30	.996417	.28	.110556	16.58	.889444	39
22	.107951	16.27	.996400	.27	.111551	16.53	.888449	38
23	.108927	16.23	.996384	.27	.112543	16.50	.887457	37
24	.109901	16.20	.996368	.28	.113533	16.47	.886467	36
25	9.110873	16.15	9.996351	.27	9.114521	16.43	0.885479	35
26	.111842	16.12	.996335	.28	.115507	16.40	.884493	34
27	.112809	16.08	.996318	.27	.116491	16.35	.883509	33
28	.113774	16.05	.996302	.28	.117472	16.33	.882528	32
29	.114737	16.02	.996285	.27	.118452	16.28	.881548	31
30	9.115698	15.97	9.996269	.28	9.119429	16.25	0.880571	30
31	.116656	15.95	.996252	.28	.120404	16.22	.879596	29
32	.117613	15.90	.996235	.27	.121377	16.18	.878623	28
33	.118567	15.87	.996219	.28	.122348	16.15	.877652	27
34	.119519	15.83	.996202	.28	.123317	16.12	.876683	26
35	9.120469	15.80	9.996185	.28	9.124284	16.08	0.875716	25
36	.121417	15.75	.996168	.28	.125249	16.03	.874751	24
37	.122362	15.73	.996151	.28	.126211	16.02	.873789	23
38	.123306	15.70	.996134	.28	.127172	15.97	.872828	22
39	.124248	15.65	.996117	.28	.128130	15.95	.871870	21
40	9.125187	15.63	9.996100	.28	9.129087	15.90	0.870913	20
41	.126125	15.58	.996083	.28	.130041	15.88	.869959	19
42	.127060	15.55	.996066	.28	.130994	15.83	.869006	18
43	.127993	15.53	.996049	.28	.131944	15.82	.868056	17
44	.128925	15.48	.996032	.28	.132893	15.77	.867107	16
45	9.129854	15.45	9.996015	.28	9.133839	15.75	0.866161	15
46	.130781	15.42	.995998	.30	.134784	15.70	.865216	14
47	.131706	15.40	.995980	.28	.135726	15.68	.864274	13
48	.132630	15.35	.995963	.28	.136667	15.63	.863333	12
49	.133551	15.32	.995946	.30	.137605	15.62	.862395	11
50	9.134470	15.28	9.995928	.28	9.138542	15.57	0.861458	10
51	.135387	15.27	.995911	.28	.139476	15.55	.860524	9
52	.136303	15.22	.995894	.30	.140409	15.52	.859591	8
53	.137216	15.20	.995876	.28	.141340	15.48	.858660	7
54	.138128	15.15	.995859	.30	.142269	15.45	.857731	6
55	9.139037	15.12	9.995841	.30	9.143196	15.42	0.856804	5
56	.139944	15.10	.995823	.28	.144121	15.38	.855879	4
57	.140850	15.07	.995806	.30	.145044	15.37	.854956	3
58	.141754	15.02	.995788	.28	.145966	15.32	.854034	2
59	.142655	15.00	.995771	.30	.146885	15.30	.853115	1
60	9.143555		9.995753		9.147803		0.852197	0
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M.

M.	Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
0	9.143555	14.97	9.995753	.30	9.147803	15.25	0.852197	60
1	.144453	14.93	.995735	.30	.148718	15.23	.851282	59
2	.145349	14.90	.995717	.30	.149632	15.20	.850368	58
3	.146243	14.88	.995699	.30	.150544	15.17	.849456	57
4	.147136	14.83	.995681	.28	.151454	15.15	.848546	56
5	9.148026	14.82	9.995664	.30	9.152363	15.10	0.847637	55
6	.148915	14.78	.995646	.30	.153269	15.08	.846731	54
7	.149802	14.73	.995628	.30	.154174	15.05	.845826	53
8	.150686	14.72	.995610	.32	.155077	15.02	.844923	52
9	.151569	14.70	.995591	.30	.155978	14.98	.844022	51
10	9.152451	14.65	9.995573	.30	9.156877	14.97	0.843123	50
11	.153330	14.63	.995555	.30	.157775	14.93	.842225	49
12	.154208	14.58	.995537	.30	.158671	14.90	.841329	48
13	.155083	14.57	.995519	.30	.159565	14.87	.840435	47
14	.155957	14.55	.995501	.32	.160457	14.83	.839543	46
15	9.156830	14.50	9.995482	.30	9.161347	14.82	0.838653	45
16	.157700	14.48	.995464	.30	.162236	14.78	.837764	44
17	.158569	14.43	.995446	.32	.163123	14.75	.836877	43
18	.159435	14.43	.995427	.30	.164008	14.73	.835992	42
19	.160301	14.38	.995409	.32	.164892	14.70	.835108	41
20	9.161164	14.35	9.995390	.30	9.165774	14.67	0.834226	40
21	.162025	14.33	.995372	.32	.166654	14.63	.833346	39
22	.162885	14.30	.995353	.32	.167532	14.62	.832468	38
23	.163743	14.28	.995334	.30	.168409	14.58	.831591	37
24	.164600	14.23	.995316	.32	.169284	14.55	.830716	36
25	9.165454	14.22	9.995297	.32	9.170157	14.53	0.829843	35
26	.166307	14.20	.995278	.30	.171029	14.50	.828971	34
27	.167159	14.15	.995260	.32	.171899	14.47	.828101	33
28	.168008	14.13	.995241	.32	.172767	14.45	.827233	32
29	.168856	14.10	.995222	.32	.173634	14.42	.826366	31
30	9.169702	14.08	9.995203	.32	9.174499	14.38	0.825501	30
31	.170547	14.03	.995184	.32	.175362	14.37	.824638	29
32	.171389	14.02	.995165	.32	.176224	14.33	.823776	28
33	.172230	14.00	.995146	.32	.177084	14.30	.822916	27
34	.173070	13.97	.995127	.32	.177942	14.28	.822058	26
35	9.173908	13.93	9.995108	.32	9.178799	14.27	0.821201	25
36	.174744	13.90	.995089	.32	.179655	14.22	.820345	24
37	.175578	13.88	.995070	.32	.180508	14.20	.819492	23
38	.176411	13.85	.995051	.32	.181360	14.18	.818640	22
39	.177242	13.83	.995032	.32	.182211	14.13	.817789	21
40	9.178072	13.80	9.995013	.33	9.183059	14.13	0.816941	20
41	.178900	13.77	.994993	.32	.183907	14.08	.816093	19
42	.179726	13.75	.994974	.32	.184752	14.08	.815248	18
43	.180551	13.72	.994955	.33	.185597	14.03	.814403	17
44	.181374	13.70	.994935	.32	.186439	14.02	.813561	16
45	9.182196	13.67	9.994916	.33	9.187280	14.00	0.812720	15
46	.183016	13.63	.994896	.32	.188120	13.97	.811880	14
47	.183834	13.62	.994877	.33	.188958	13.93	.811042	13
48	.184651	13.58	.994857	.32	.189794	13.92	.810206	12
49	.185466	13.57	.994838	.33	.190629	13.88	.809371	11
50	9.186280	13.53	9.994818	.33	9.191462	13.87	0.808538	10
51	.187092	13.52	.994798	.32	.192294	13.83	.807706	9
52	.187903	13.48	.994779	.33	.193124	13.82	.806876	8
53	.188712	13.45	.994759	.33	.193953	13.78	.806047	7
54	.189519	13.43	.994739	.32	.194780	13.77	.805220	6
55	9.190325	13.42	9.994720	.33	9.195606	13.73	0.804394	5
56	.191130	13.38	.994700	.33	.196430	13.72	.803570	4
57	.191933	13.35	.994680	.33	.197253	13.68	.802747	3
58	.192734	13.33	.994660	.33	.198074	13.67	.801926	2
59	.193534	13.30	.994640	.33	.198894	13.65	.801106	1
60	9.194332		9.994620		9.199713		0.800287	0
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M.

M.	Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
0	9.194332	13.28	9.994620	.33	9.199713	13.60	0.800287	60
1	.195129	13.27	.994600	.33	.200529	13.60	.799471	59
2	.195925	13.23	.994580	.33	.201345	13.57	.798655	58
3	.196719	13.20	.994560	.33	.202159	13.53	.797841	57
4	.197511	13.18	.994540	.35	.202971	13.52	.797029	56
5	9.198302	13.15	9.994519	.33	9.203782	13.50	0.796218	55
6	.199091	13.13	.994499	.33	.204592	13.47	.795408	54
7	.199879	13.12	.994479	.33	.205400	13.45	.794600	53
8	.200666	13.08	.994459	.35	.206207	13.43	.793793	52
9	.201451	13.05	.994438	.33	.207013	13.40	.792987	51
10	9.202234	13.05	9.994418	.33	9.207817	13.37	0.792183	50
11	.203017	13.00	.994398	.35	.208619	13.35	.791381	49
12	.203797	13.00	.994377	.33	.209420	13.33	.790580	48
13	.204577	12.95	.994357	.35	.210220	13.30	.789780	47
14	.205354	12.95	.994336	.33	.211018	13.28	.788982	46
15	9.206131	12.92	9.994316	.35	9.211815	13.27	0.788185	45
16	.206906	12.88	.994295	.35	.212611	13.23	.787389	44
17	.207679	12.88	.994274	.33	.213405	13.22	.786595	43
18	.208452	12.83	.994254	.35	.214198	13.18	.785802	42
19	.209222	12.83	.994233	.35	.214989	13.18	.785011	41
20	9.209992	12.80	9.994212	.35	9.215780	13.13	0.784220	40
21	.210760	12.77	.994191	.33	.216568	13.13	.783432	39
22	.211526	12.75	.994171	.35	.217356	13.10	.782644	38
23	.212291	12.73	.994150	.35	.218142	13.07	.781858	37
24	.213055	12.72	.994129	.35	.218926	13.07	.781074	36
25	9.213818	12.68	9.994108	.35	9.219710	13.03	0.780290	35
26	.214579	12.65	.994087	.35	.220492	13.00	.779508	34
27	.215338	12.65	.994066	.35	.221272	13.00	.778728	33
28	.216097	12.62	.994045	.35	.222052	12.97	.777948	32
29	.216854	12.58	.994024	.35	.222830	12.95	.777170	31
30	9.217609	12.57	9.994003	.35	9.223607	12.92	0.776393	30
31	.218363	12.55	.993982	.37	.224382	12.90	.775618	29
32	.219116	12.53	.993960	.35	.225156	12.88	.774844	28
33	.219868	12.50	.993939	.35	.225929	12.85	.774071	27
34	.220618	12.48	.993918	.35	.226700	12.85	.773300	26
35	9.221367	12.47	9.993897	.37	9.227471	12.80	0.772529	25
36	.222115	12.43	.993875	.35	.228239	12.80	.771761	24
37	.222861	12.42	.993854	.37	.229007	12.77	.770993	23
38	.223606	12.38	.993832	.35	.229773	12.77	.770227	22
39	.224349	12.38	.993811	.37	.230539	12.72	.769461	21
40	9.225092	12.35	9.993789	.35	9.231302	12.72	0.768698	20
41	.225833	12.33	.993768	.37	.232065	12.68	.767935	19
42	.226573	12.30	.993746	.35	.232826	12.67	.767174	18
43	.227311	12.28	.993725	.37	.233586	12.65	.766414	17
44	.228048	12.27	.993703	.37	.234345	12.63	.765655	16
45	9.228784	12.23	9.993681	.35	9.235103	12.60	0.764897	15
46	.229518	12.23	.993660	.37	.235859	12.58	.764141	14
47	.230252	12.20	.993638	.37	.236614	12.57	.763386	13
48	.230984	12.18	.993616	.37	.237368	12.53	.762632	12
49	.231715	12.15	.993594	.37	.238120	12.53	.761880	11
50	9.232444	12.13	9.993572	.37	9.238872	12.50	0.761128	10
51	.233172	12.12	.993550	.37	.239622	12.48	.760378	9
52	.233899	12.10	.993528	.37	.240371	12.45	.759629	8
53	.234625	12.07	.993506	.37	.241118	12.45	.758882	7
54	.235349	12.07	.993484	.37	.241865	12.42	.758135	6
55	9.236073	12.03	9.993462	.37	9.242610	12.40	0.757390	5
56	.236795	12.00	.993440	.37	.243354	12.38	.756646	4
57	.237515	12.00	.993418	.37	.244097	12.37	.755903	3
58	.238235	11.97	.993396	.37	.244839	12.33	.755161	2
59	.238953	11.95	.993374	.38	.245579	12.33	.754421	1
60	9.239670		9.993351		9.246319		0.753681	0
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M.

M.	Sin.	D. 1".	Cos.	D. 1".	Tan.	D. 1".	Cot.	
0	9.239670	11.93	9.993351	.37	9.246319	12.30	0.753681	60
1	.240386	11.92	.993329	.37	.247057	12.28	.752943	59
2	.241101	11.88	.993307	.38	.247794	12.27	.752206	58
3	.241814	11.87	.993284	.37	.248530	12.23	.751470	57
4	.242526	11.85	.993262	.37	.249264	12.23	.750736	56
5	9.243237	11.83	9.993240	.38	9.249998	12.20	0.750002	55
6	.243947	11.82	.993217	.37	.250730	12.18	.749270	54
7	.244656	11.78	.993195	.38	.251461	12.17	.748539	53
8	.245363	11.77	.993172	.38	.252191	12.15	.747809	52
9	.246069	11.77	.993149	.37	.252920	12.13	.747080	51
10	9.246775	11.72	9.993127	.38	9.253648	12.10	0.746352	50
11	.247478	11.72	.993104	.38	.254374	12.10	.745626	49
12	.248181	11.70	.993081	.37	.255100	12.07	.744900	48
13	.248883	11.67	.993059	.38	.255824	12.05	.744176	47
14	.249583	11.65	.993036	.38	.256547	12.03	.743453	46
15	9.250282	11.63	9.993013	.38	9.257269	12.02	0.742731	45
16	.250980	11.62	.992990	.38	.257990	12.00	.742010	44
17	.251677	11.60	.992967	.38	.258710	11.98	.741290	43
18	.252373	11.57	.992944	.38	.259429	11.95	.740571	42
19	.253067	11.57	.992921	.38	.260146	11.95	.739854	41
20	9.253761	11.53	9.992898	.38	9.260863	11.92	0.739137	40
21	.254453	11.52	.992875	.38	.261578	11.90	.738422	39
22	.255144	11.50	.992852	.38	.262292	11.88	.737708	38
23	.255834	11.48	.992829	.38	.263005	11.87	.736995	37
24	.256523	11.47	.992806	.38	.263717	11.85	.736283	36
25	9.257211	11.45	9.992783	.40	9.264428	11.83	0.735572	35
26	.257898	11.42	.992759	.38	.265138	11.82	.734862	34
27	.258583	11.42	.992736	.38	.265847	11.80	.734153	33
28	.259268	11.38	.992713	.38	.266555	11.77	.733445	32
29	.259951	11.37	.992690	.40	.267261	11.77	.732739	31
30	9.260633	11.35	9.992666	.38	9.267967	11.73	0.732033	30
31	.261314	11.33	.992643	.40	.268671	11.73	.731329	29
32	.261994	11.32	.992619	.38	.269375	11.70	.730625	28
33	.262673	11.30	.992596	.40	.270077	11.70	.729923	27
34	.263351	11.27	.992572	.38	.270779	11.67	.729221	26
35	9.264027	11.27	9.992549	.40	9.271479	11.65	0.728521	25
36	.264703	11.23	.992525	.40	.272178	11.63	.727822	24
37	.265377	11.23	.992501	.38	.272876	11.62	.727124	23
38	.266051	11.20	.992478	.40	.273573	11.60	.726427	22
39	.266723	11.20	.992454	.40	.274269	11.58	.725731	21
40	9.267395	11.17	9.992430	.40	9.274964	11.57	0.725036	20
41	.268065	11.15	.992406	.40	.275658	11.55	.724342	19
42	.268734	11.13	.992382	.38	.276351	11.53	.723649	18
43	.269402	11.12	.992359	.40	.277043	11.52	.722957	17
44	.270069	11.10	.992335	.40	.277734	11.50	.722266	16
45	9.270735	11.08	9.992311	.40	9.278424	11.48	0.721576	15
46	.271400	11.07	.992287	.40	.279113	11.47	.720887	14
47	.272064	11.03	.992263	.40	.279801	11.45	.720199	13
48	.272726	11.03	.992239	.42	.280488	11.43	.719512	12
49	.273388	11.02	.992214	.40	.281174	11.40	.718826	11
50	9.274049	10.98	9.992190	.40	9.281858	11.40	0.718142	10
51	.274708	10.98	.992166	.40	.282542	11.38	.717458	9
52	.275367	10.97	.992142	.40	.283225	11.37	.716775	8
53	.276025	10.93	.992118	.42	.283907	11.35	.716093	7
54	.276681	10.93	.992093	.40	.284588	11.33	.715412	6
55	9.277337	10.90	9.992069	.42	9.285268	11.32	0.714732	5
56	.277991	10.90	.992044	.40	.285947	11.28	.714053	4
57	.278645	10.87	.992020	.40	.286624	11.28	.713376	3
58	.279297	10.85	.991996	.42	.287301	11.27	.712699	2
59	.279948	10.85	.991971	.40	.287977	11.25	.712023	1
60	9.280599		9.991947		9.288652		0.711348	0
	Cos.	D. 1".	Sin.	D. 1".	Cot.	D. 1".	Tan.	M.

M.	Sin.	D. 1".	Cos.	D. 1".	Tan.	D. 1".	Cot.	
0	9.280599	10.82	9.991947	.42	9.288652	11.23	0.711348	60
1	.281248	10.82	.991922	.42	.289326	11.22	.710674	59
2	.281897	10.78	.991897	.40	.289999	11.20	.710001	58
3	.282544	10.77	.991873	.42	.290671	11.18	.709329	57
4	.283190	10.77	.991848	.42	.291342	11.18	.708658	56
5	9.283836	10.73	9.991823	.40	9.292013	11.15	0.707987	55
6	.284480	10.73	.991799	.42	.292682	11.13	.707318	54
7	.285124	10.70	.991774	.42	.293350	11.12	.706650	53
8	.285766	10.70	.991749	.42	.294017	11.12	.705983	52
9	.286408	10.67	.991724	.42	.294684	11.08	.705316	51
10	9.287048	10.67	9.991699	.42	9.295349	11.07	0.704651	50
11	.287688	10.63	.991674	.42	.296013	11.07	.703987	49
12	.288326	10.63	.991649	.42	.296677	11.03	.703323	48
13	.288964	10.60	.991624	.42	.297339	11.03	.702661	47
14	.289600	10.60	.991599	.42	.298001	11.02	.701999	46
15	9.290236	10.57	9.991574	.42	9.298662	11.00	0.701338	45
16	.290870	10.57	.991549	.42	.299322	10.97	.700678	44
17	.291504	10.55	.991524	.43	.299980	10.97	.700020	43
18	.292137	10.52	.991498	.42	.300638	10.95	.699362	42
19	.292768	10.52	.991473	.42	.301295	10.93	.698705	41
20	9.293399	10.50	9.991448	.43	9.301951	10.93	0.698049	40
21	.294029	10.48	.991422	.42	.302607	10.90	.697393	39
22	.294658	10.47	.991397	.42	.303261	10.88	.696739	38
23	.295286	10.45	.991372	.43	.303914	10.88	.696086	37
24	.295913	10.43	.991346	.42	.304567	10.85	.695433	36
25	9.296539	10.42	9.991321	.43	9.305218	10.85	0.694782	35
26	.297164	10.40	.991295	.42	.305869	10.83	.694131	34
27	.297788	10.40	.991270	.43	.306519	10.82	.693481	33
28	.298412	10.37	.991244	.43	.307168	10.80	.692832	32
29	.299034	10.35	.991218	.42	.307816	10.78	.692184	31
30	9.299655	10.35	9.991193	.43	9.308463	10.77	0.691537	30
31	.300276	10.32	.991167	.43	.309109	10.75	.690891	29
32	.300895	10.32	.991141	.43	.309754	10.75	.690246	28
33	.301514	10.30	.991115	.42	.310399	10.72	.689601	27
34	.302132	10.27	.991090	.43	.311042	10.72	.688958	26
35	9.302748	10.27	9.991064	.43	9.311685	10.70	0.688315	25
36	.303364	10.25	.991038	.43	.312327	10.68	.687673	24
37	.303979	10.23	.991012	.43	.312968	10.67	.687032	23
38	.304593	10.23	.990986	.43	.313608	10.65	.686392	22
39	.305207	10.20	.990960	.43	.314247	10.63	.685753	21
40	9.305819	10.18	9.990934	.43	9.314885	10.63	0.685115	20
41	.306430	10.18	.990908	.43	.315523	10.60	.684477	19
42	.307041	10.15	.990882	.45	.316159	10.60	.683841	18
43	.307650	10.15	.990855	.43	.316795	10.58	.683205	17
44	.308259	10.13	.990829	.43	.317430	10.57	.682570	16
45	9.308867	10.12	9.990803	.43	9.318064	10.55	0.681936	15
46	.309474	10.10	.990777	.45	.318697	10.55	.681303	14
47	.310080	10.08	.990750	.43	.319330	10.52	.680670	13
48	.310685	10.07	.990724	.45	.319961	10.52	.680039	12
49	.311289	10.07	.990697	.43	.320592	10.50	.679408	11
50	9.311893	10.03	9.990671	.43	9.321222	10.48	0.678778	10
51	.312495	10.03	.990645	.45	.321851	10.47	.678149	9
52	.313097	10.02	.990618	.45	.322479	10.45	.677521	8
53	.313698	9.98	.990591	.43	.323106	10.45	.676894	7
54	.314297	10.00	.990565	.45	.323733	10.42	.676267	6
55	9.314897	9.97	9.990538	.45	9.324358	10.42	0.675642	5
56	.315495	9.95	.990511	.43	.324983	10.40	.675017	4
57	.316092	9.95	.990485	.45	.325607	10.40	.674393	3
58	.316689	9.92	.990458	.45	.326231	10.37	.673769	2
59	.317284	9.92	.990431	.45	.326853	10.37	.673147	1
60	9.317879		9.990404		9.327475		0.672525	0
	Cos.	D. 1".	Sin.	D. 1".	Cot.	D. 1".	Tan.	M.

M.	Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
0	9.317879	9.90	9.990404	.43	9.327475	10.33	0.672525	60
1	.318473	9.88	.990378	.45	.328095	10.33	.671905	59
2	.319066	9.87	.990351	.45	.328715	10.32	.671285	58
3	.319658	9.85	.990324	.45	.329334	10.32	.670666	57
4	.320249	9.85	.990297	.45	.329953	10.28	.670047	56
5	9.320840	9.83	9.990270	.45	9.330570	10.28	0.669430	55
6	.321430	9.82	.990243	.47	.331187	10.27	.668813	54
7	.322019	9.80	.990215	.45	.331803	10.25	.668197	53
8	.322607	9.78	.990188	.45	.332418	10.25	.667582	52
9	.323194	9.77	.990161	.45	.333033	10.22	.666967	51
10	9.323780	9.77	9.990134	.45	9.333646	10.22	0.666354	50
11	.324366	9.73	.990107	.47	.334259	10.20	.665741	49
12	.324950	9.73	.990079	.45	.334871	10.18	.665129	48
13	.325534	9.72	.990052	.45	.335482	10.18	.664518	47
14	.326117	9.72	.990025	.47	.336093	10.15	.663907	46
15	9.326700	9.68	9.989997	.45	9.336702	10.15	0.663298	45
16	.327281	9.68	.989970	.47	.337311	10.13	.662689	44
17	.327862	9.67	.989942	.45	.337919	10.13	.662081	43
18	.328442	9.65	.989915	.47	.338527	10.10	.661473	42
19	.329021	9.63	.989887	.45	.339133	10.10	.660867	41
20	9.329599	9.62	9.989860	.47	9.339739	10.08	0.660261	40
21	.330176	9.62	.989832	.47	.340344	10.07	.659656	39
22	.330753	9.60	.989804	.45	.340948	10.07	.659052	38
23	.331329	9.57	.989777	.47	.341552	10.05	.658448	37
24	.331903	9.58	.989749	.47	.342155	10.03	.657845	36
25	9.332478	9.55	9.989721	.47	9.342757	10.02	0.657243	35
26	.333051	9.55	.989693	.47	.343358	10.00	.656642	34
27	.333624	9.52	.989665	.47	.343958	10.00	.656042	33
28	.334195	9.53	.989637	.45	.344558	9.98	.655442	32
29	.334767	9.50	.989610	.47	.345157	9.97	.654843	31
30	9.335337	9.48	9.989582	.48	9.345755	9.97	0.654245	30
31	.335906	9.48	.989553	.47	.346353	9.93	.653647	29
32	.336475	9.47	.989525	.47	.346949	9.93	.653051	28
33	.337043	9.45	.989497	.47	.347545	9.93	.652455	27
34	.337610	9.43	.989469	.47	.348141	9.90	.651859	26
35	9.338176	9.43	9.989441	.47	9.348735	9.90	0.651265	25
36	.338742	9.42	.989413	.47	.349329	9.88	.650671	24
37	.339307	9.40	.989385	.48	.349922	9.87	.650078	23
38	.339871	9.38	.989356	.47	.350514	9.87	.649486	22
39	.340434	9.37	.989328	.47	.351106	9.85	.648894	21
40	9.340996	9.37	9.989300	.48	9.351697	9.83	0.648303	20
41	.341558	9.35	.989271	.47	.352287	9.82	.647713	19
42	.342119	9.33	.989243	.48	.352876	9.82	.647124	18
43	.342679	9.33	.989214	.47	.353465	9.80	.646535	17
44	.343239	9.30	.989186	.48	.354053	9.78	.645947	16
45	9.343797	9.30	9.989157	.48	9.354640	9.78	0.645360	15
46	.344355	9.28	.989128	.47	.355227	9.77	.644773	14
47	.344912	9.28	.989100	.48	.355813	9.75	.644187	13
48	.345469	9.25	.989071	.48	.356398	9.73	.643602	12
49	.346024	9.25	.989042	.47	.356982	9.73	.643018	11
50	9.346579	9.25	9.989014	.48	9.357566	9.72	0.642434	10
51	.347134	9.22	.988985	.48	.358149	9.70	.641851	9
52	.347687	9.22	.988956	.48	.358731	9.70	.641269	8
53	.348240	9.20	.988927	.48	.359313	9.67	.640687	7
54	.348792	9.18	.988898	.48	.359893	9.68	.640107	6
55	9.349343	9.17	9.988869	.48	9.360474	9.65	0.639526	5
56	.349893	9.17	.988840	.48	.361053	9.65	.638947	4
57	.350443	9.15	.988811	.48	.361632	9.63	.638368	3
58	.350992	9.13	.988782	.48	.362210	9.62	.637790	2
59	.351540	9.13	.988753	.48	.362787	9.62	.637213	1
60	9.352088		9.988724		9.363364		0.636636	0
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M.

M	Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
0	9.352088	9.12	9.988724	.48	9.363364	9.60	0.636636	60
1	.352635	9.10	.988695	.48	.363940	9.58	.636060	59
2	.353181	9.08	.988666	.50	.364515	9.58	.635485	58
3	.353726	9.08	.988636	.48	.365090	9.57	.634910	57
4	.354271	9.07	.988607	.48	.365664	9.55	.634336	56
5	9.354815	9.05	9.988578	.50	9.366237	9.55	0.633763	55
6	.355358	9.05	.988548	.48	.366810	9.53	.633190	54
7	.355901	9.03	.988519	.50	.367382	9.52	.632618	53
8	.356443	9.02	.988489	.48	.367953	9.52	.632047	52
9	.356984	9.00	.988460	.50	.368524	9.50	.631476	51
10	9.357524	9.00	9.988430	.48	9.369094	9.48	0.630906	50
11	.358064	8.98	.988401	.50	.369663	9.48	.630337	49
12	.358603	8.97	.988371	.48	.370232	9.45	.629768	48
13	.359141	8.95	.988342	.50	.370799	9.47	.629201	47
14	.359678	8.95	.988312	.50	.371367	9.43	.628633	46
15	9.360215	8.95	9.988282	.50	9.371933	9.43	0.628067	45
16	.360752	8.92	.988252	.48	.372499	9.42	.627501	44
17	.361287	8.92	.988223	.50	.373064	9.42	.626936	43
18	.361822	8.90	.988193	.50	.373629	9.40	.626371	42
19	.362356	8.88	.988163	.50	.374193	9.38	.625807	41
20	9.362889	8.88	9.988133	.50	9.374756	9.38	0.625244	40
21	.363422	8.87	.988103	.50	.375319	9.37	.624681	39
22	.363954	8.85	.988073	.50	.375881	9.35	.624119	38
23	.364485	8.85	.988043	.50	.376442	9.35	.623558	37
24	.365016	8.83	.988013	.50	.377003	9.33	.622997	36
25	9.365546	8.82	9.987983	.50	9.377563	9.32	0.622437	35
26	.366075	8.82	.987953	.52	.378122	9.32	.621878	34
27	.366604	8.78	.987922	.50	.378681	9.30	.621319	33
28	.367131	8.80	.987892	.50	.379239	9.30	.620761	32
29	.367659	8.77	.987862	.50	.379797	9.28	.620203	31
30	9.368185	8.77	9.987832	.52	9.380354	9.27	0.619646	30
31	.368711	8.75	.987801	.50	.380910	9.27	.619090	29
32	.369236	8.75	.987771	.52	.381466	9.23	.618534	28
33	.369761	8.73	.987740	.50	.382020	9.25	.617980	27
34	.370285	8.72	.987710	.52	.382575	9.23	.617425	26
35	9.370808	8.70	9.987679	.50	9.383129	9.22	0.616871	25
36	.371330	8.70	.987649	.52	.383682	9.20	.616318	24
37	.371852	8.68	.987618	.50	.384234	9.20	.615766	23
38	.372373	8.68	.987588	.52	.384786	9.18	.615214	22
39	.372894	8.67	.987557	.52	.385337	9.18	.614663	21
40	9.373414	8.65	9.987526	.50	9.385888	9.17	0.614112	20
41	.373933	8.65	.987496	.52	.386438	9.15	.613562	19
42	.374452	8.63	.987465	.52	.386987	9.15	.613013	18
43	.374970	8.62	.987434	.52	.387536	9.13	.612464	17
44	.375487	8.60	.987403	.52	.388084	9.12	.611916	16
45	9.376003	8.60	9.987372	.52	9.388631	9.12	0.611369	15
46	.376519	8.60	.987341	.52	.389178	9.10	.610822	14
47	.377035	8.57	.987310	.52	.389724	9.10	.610276	13
48	.377549	8.57	.987279	.52	.390270	9.08	.609730	12
49	.378063	8.57	.987248	.52	.390815	9.08	.609185	11
50	9.378577	8.53	9.987217	.52	9.391360	9.05	0.608640	10
51	.379089	8.53	.987186	.52	.391903	9.07	.608097	9
52	.379601	8.53	.987155	.52	.392447	9.03	.607553	8
53	.380113	8.52	.987124	.53	.392989	9.03	.607011	7
54	.380624	8.50	.987092	.52	.393531	9.03	.606469	6
55	9.381134	8.48	9.987061	.52	9.394073	9.02	0.605927	5
56	.381643	8.48	.987030	.53	.394614	9.00	.605386	4
57	.382152	8.48	.986998	.52	.395154	9.00	.604846	3
58	.382661	8.45	.986967	.52	.395694	8.98	.604306	2
59	.383168	8.45	.986936	.53	.396233	8.97	.603767	1
60	9.383675		9.986904		9.396771		0.603229	0
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M.

[illegible]	Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
0	9.383675	8.45	9.986904	.52	9.396771	8.97	0.603229	[illegible]
1	.384182	8.42	.986873	.53	.397309	8.95	.602691	59
2	.384687	8.42	.986841	.53	.397846	8.95	.602154	58
3	.385192	8.42	.986809	.52	.398383	8.93	.601617	57
4	.385697	8.40	.986778	.53	.398919	8.93	.601081	56
5	9.386201	8.38	9.986746	.53	9.399455	8.92	0.600545	55
6	.386704	8.38	.986714	.52	.399990	8.90	.600010	[illegible]
7	.387207	8.37	.986683	.53	.400524	8.90	.599476	53
8	.387709	8.35	.986651	.53	.401058	8.88	.598942	52
9	.388210	8.35	.986619	.53	.401591	8.88	.598409	51
10	9.388711	8.33	9.986587	.53	9.402124	8.87	0.597876	50
11	.389211	8.33	.986555	.53	.402656	8.85	.597344	49
12	.389711	8.32	.986523	.53	.403187	8.85	.596813	48
13	.390210	8.30	.986491	.53	.403718	8.85	.596282	47
14	.390708	8.30	.986459	.53	.404249	8.82	.595751	46
15	9.391206	8.28	9.986427	.53	9.404778	8.83	0.595222	45
16	.391703	8.27	.986395	.53	.405308	8.80	.594692	44
17	.392199	8.27	.986363	.53	.405836	8.80	.594164	43
18	.392695	8.27	.986331	[illegible]	.406364	8.80	.593636	42
[illegible]	.393191	8.23	.986299	.55	.406892	8.78	.593108	41
20	9.393685	8.23	9.986266	.53	9.407419	8.77	0.592581	40
21	.394179	8.23	.986234	.53	.407945	8.77	.592055	39
22	.394673	8.22	.986202	.55	.408471	8.75	.591529	38
23	.395166	8.20	.986169	.53	.408996	8.75	.591004	37
24	.395658	8.20	.986137	.55	.409521	8.73	.590479	36
25	9.396150	8.18	9.986104	.53	9.410045	8.73	0.589955	35
26	.396641	8.18	.986072	.55	.410569	8.72	.589431	34
27	.397132	8.15	.986039	.53	.411092	8.72	.588908	33
28	.397621	8.17	.986007	.55	.411615	8.70	.588385	32
29	.398111	8.15	.985974	.53	.412137	8.68	.587863	31
30	9.398600	8.13	9.985942	.55	9.412658	8.68	0.587342	30
31	.399088	8.12	.985909	.55	.413179	8.67	.586821	29
32	.399575	8.12	.985876	.55	.413699	8.67	.586301	28
33	.400062	8.12	.985843	.53	.414219	8.65	.585781	27
34	.400549	8.10	.985811	.55	.414738	8.65	.585262	26
35	9.401035	8.08	9.985778	.55	9.415257	8.63	0.584743	25
36	.401520	8.08	.985745	.55	.415775	8.63	.584225	24
37	.402005	8.07	.985712	.55	.416293	8.62	.583707	23
38	.402489	8.05	.985679	.55	.416810	8.60	.583190	22
39	.402972	8.05	.985646	.55	.417326	8.60	.582674	21
40	9.403455	8.05	9.985613	.55	9.417842	8.60	0.582158	20
41	.403938	8.03	.985580	.55	.418358	8.58	.581642	19
42	.404420	8.02	.985547	.55	.418873	8.57	.581127	18
43	.404901	8.02	.985514	.57	.419387	8.57	.580613	17
44	.405382	8.00	.985480	.55	.419901	8.57	.580099	16
45	9.405862	7.98	9.985447	.55	9.420415	8.53	0.579585	15
46	.406341	7.98	.985414	.55	.420927	8.55	.579073	14
47	.406820	7.98	.985381	.57	.421440	8.53	.578560	13
48	.407299	7.97	.985347	.55	.421952	8.52	.578048	12
49	.407777	7.95	.985314	.57	.422463	8.52	.577537	11
50	9.408254	7.95	9.985280	.55	9.422974	8.50	0.577026	10
51	.408731	7.93	.985247	.57	.423484	8.48	.576516	9
52	.409207	7.92	.985213	.55	.423993	8.50	.576007	8
53	.409682	7.92	.985180	.57	.424503	8.47	.575497	7
54	.410157	7.92	.985146	.55	.425011	8.47	.574989	6
55	9.410632	7.90	9.985113	.57	9.425519	8.47	0.574481	5
56	.411106	7.88	.985079	.57	.426027	8.45	.573973	4
57	.411579	7.88	.985045	.57	.426534	8.45	.573466	3
58	.412052	7.87	.985011	.55	.427041	8.43	.572959	2
59	.412524	7.87	.984978	.57	.427547	8.42	.572453	1
60	9.412996		9.984944		9.428052		0.571948	0
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M'

M.	Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
0	9.412996	7.85	9.984944	.57	9.428052	8.43	0.571948	60
1	.413467	7.85	.984910	.57	.428558	8.40	.571442	59
2	.413938	7.83	.984876	.57	.429062	8.40	.570938	58
3	.414408	7.83	.984842	.57	.429566	8.40	.570434	57
4	.414878	7.82	.984808	.57	.430070	8.38	.569930	56
5	9.415347	7.80	9.984774	.57	9.430573	8.37	0.569427	55
6	.415815	7.80	.984740	.57	.431075	8.37	.568925	54
7	.416283	7.80	.984706	.57	.431577	8.37	.568423	53
8	.416751	7.77	.984672	.57	.432079	8.35	.567921	52
9	.417217	7.78	.984638	.58	.432580	8.33	.567420	51
10	9.417684	7.77	9.984603	.57	9.433080	8.33	0.566920	50
11	.418150	7.75	.984569	.57	.433580	8.33	.566420	49
12	.418615	7.73	.984535	.58	.434080	8.32	.565920	48
13	.419079	7.75	.984500	.57	.434579	8.32	.565421	47
14	.419544	7.72	.984466	.57	.435078	8.30	.564922	46
15	9.420007	7.72	9.984432	.58	9.435576	8.28	0.564424	45
16	.420470	7.72	.984397	.57	.436073	8.28	.563927	44
17	.420933	7.70	.984363	.58	.436570	8.28	.563430	43
18	.421395	7.70	.984328	.57	.437067	8.27	.562933	42
19	.421857	7.68	.984294	.58	.437563	8.27	.562437	41
20	9.422318	7.67	9.984259	.58	9.438059	8.25	0.561941	40
21	.422778	7.67	.984224	.57	.438554	8.23	.561446	39
22	.423238	7.65	.984190	.58	.439048	8.25	.560952	38
23	.423697	7.65	.984155	.58	.439543	8.22	.560457	37
24	.424156	7.65	.984120	.58	.440036	8.22	.559964	36
25	9.424615	7.63	9.984085	.58	9.440529	8.22	0.559471	35
26	.425073	7.62	.984050	.58	.441022	8.20	.558978	34
27	.425530	7.62	.984015	.57	.441514	8.20	.558486	33
28	.425987	7.60	.983981	.58	.442006	8.18	.557994	32
29	.426443	7.60	.983946	.58	.442497	8.18	.557503	31
30	9.426899	7.58	9.983911	.60	9.442988	8.18	0.557012	30
31	.427354	7.58	.983875	.58	.443479	8.15	.556521	29
32	.427809	7.57	.983840	.58	.443968	8.17	.556032	28
33	.428263	7.57	.983805	.58	.444458	8.15	.555542	27
34	.428717	7.55	.983770	.58	.444947	8.13	.555053	26
35	9.429170	7.55	9.983735	.58	9.445435	8.13	0.554565	25
36	.429623	7.53	.983700	.60	.445923	8.13	.554077	24
37	.430075	7.53	.983664	.58	.446411	8.12	.553589	23
38	.430527	7.52	.983629	.58	.446898	8.10	.553102	22
39	.430978	7.52	.983594	.60	.447384	8.10	.552616	21
40	9.431429	7.50	9.983558	.58	9.447870	8.10	0.552130	20
41	.431879	7.50	.983523	.60	.448356	8.08	.551644	19
42	.432329	7.48	.983487	.58	.448841	8.08	.551159	18
43	.432778	7.47	.983452	.60	.449326	8.07	.550674	17
44	.433226	7.48	.983416	.58	.449810	8.07	.550190	16
45	9.433675	7.45	9.983381	.60	9.450294	8.05	0.549706	15
46	.434122	7.45	.983345	.60	.450777	8.05	.549223	14
47	.434569	7.45	.983309	.60	.451260	8.05	.548740	13
48	.435016	7.43	.983273	.58	.451743	8.03	.548257	12
49	.435462	7.43	.983238	.60	.452225	8.02	.547775	11
50	9.435908	7.42	9.983202	.60	9.452706	8.02	0.547294	10
51	.436353	7.42	.983166	.60	.453187	8.02	.546813	9
52	.436798	7.40	.983130	.60	.453668	8.00	.546332	8
53	.437242	7.40	.983094	.60	.454148	8.00	.545852	7
54	.437686	7.38	.983058	.60	.454628	7.98	.545372	6
55	9.438129	7.38	9.983022	.60	9.455107	7.98	0.544893	5
56	.438572	7.37	.982986	.60	.455586	7.97	.544414	4
57	.439014	7.37	.982950	.60	.456064	7.97	.543936	3
58	.439456	7.35	.982914	.60	.456542	7.95	.543458	2
59	.439897	7.35	.982878	.60	.457019	7.95	.542981	1
60	9.440338		9.982842		9.457496		0.542504	0
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M.

M.	Sin.	D. 1".	Cos.	D. 1".	Tan.	D. 1".	Cot.	
0	9.440338	7.33	9.982842	.62	9.457496	7.95	0.542504	60
1	.440778	7.33	.982805	.60	.457973	7.93	.542027	59
2	.441218	7.33	.982769	.60	.458449	7.93	.541551	58
3	.441658	7.30	.982733	.62	.458925	7.92	.541075	57
4	.442096	7.32	.982696	.60	.459400	7.92	.540600	56
5	9.442535	7.30	9.982660	.60	9.459875	7.90	0.540125	55
6	.442973	7.28	.982624	.62	.460349	7.90	.539651	54
7	.443410	7.28	.982587	.60	.460823	7.90	.539177	53
8	.443847	7.28	.982551	.62	.461297	7.88	.538703	52
9	.444284	7.27	.982514	.62	.461770	7.87	.538230	51
10	9.444720	7.25	9.982477	.60	9.462242	7.88	0.537758	50
11	.445155	7.25	.982441	.62	.462715	7.85	.537285	49
12	.445590	7.25	.982404	.62	.463186	7.87	.536814	48
13	.446025	7.23	.982367	.60	.463658	7.83	.536342	47
14	.446459	7.23	.982331	.62	.464128	7.85	.535872	46
15	9.446893	7.22	9.982294	.62	9.464599	7.83	0.535401	45
16	.447326	7.22	.982257	.62	.465069	7.83	.534931	44
17	.447759	7.20	.982220	.62	.465539	7.82	.534461	43
18	.448191	7.20	.982183	.62	.466008	7.82	.533992	42
19	.448623	7.18	.982146	.62	.466477	7.80	.533523	41
20	9.449054	7.18	9.982109	.62	9.466945	7.80	0.533055	40
21	.449485	7.17	.982072	.62	.467413	7.78	.532587	39
22	.449915	7.17	.982035	.62	.467880	7.78	.532120	38
23	.450345	7.17	.981998	.62	.468347	7.78	.531653	37
24	.450775	7.15	.981961	.62	.468814	7.77	.531186	36
25	9.451204	7.13	9.981924	.63	9.469280	7.77	0.530720	35
26	.451632	7.13	.981886	.62	.469746	7.75	.530254	34
27	.452060	7.13	.981849	.62	.470211	7.75	.529789	33
28	.452488	7.12	.981812	.63	.470676	7.75	.529324	32
29	.452915	7.12	.981774	.62	.471141	7.73	.528859	31
30	9.453342	7.10	9.981737	.62	9.471605	7.73	0.528395	30
31	.453768	7.10	.981700	.63	.472069	7.72	.527931	29
32	.454194	7.08	.981662	.62	.472532	7.72	.527468	28
33	.454619	7.08	.981625	.63	.472995	7.70	.527005	27
34	.455044	7.08	.981587	.63	.473457	7.70	.526543	26
35	9.455469	7.07	9.981549	.62	9.473919	7.70	0.526081	25
36	.455893	7.05	.981512	.63	.474381	7.68	.525619	24
37	.456316	7.05	.981474	.63	.474842	7.68	.525158	23
38	.456739	7.05	.981436	.62	.475303	7.67	.524697	22
39	.457162	7.03	.981399	.63	.475763	7.67	.524237	21
40	9.457584	7.03	9.981361	.63	9.476223	7.67	0.523777	20
41	.458006	7.02	.981323	.63	.476683	7.65	.523317	19
42	.458427	7.02	.981285	.63	.477142	7.65	.522858	18
43	.458848	7.00	.981247	.63	.477601	7.63	.522399	17
44	.459268	7.00	.981209	.63	.478059	7.63	.521941	16
45	9.459688	7.00	9.981171	.63	9.478517	7.63	0.521483	15
46	.460108	6.98	.981133	.63	.478975	7.62	.521025	14
47	.460527	6.98	.981095	.63	.479432	7.62	.520568	13
48	.460946	6.97	.981057	.63	.479889	7.60	.520111	12
49	.461364	6.97	.981019	.63	.480345	7.60	.519655	11
50	9.461782	6.95	9.980981	.65	9.480801	7.60	0.519199	10
51	.462199	6.95	.980942	.63	.481257	7.58	.518743	9
52	.462616	6.93	.980904	.63	.481712	7.58	.518288	8
53	.463032	6.93	.980866	.65	.482167	7.57	.517833	7
54	.463448	6.93	.980827	.63	.482621	7.57	.517379	6
55	9.463864	6.92	9.980789	.65	9.483075	7.57	0.516925	5
56	.464279	6.92	.980750	.63	.483529	7.55	.516471	4
57	.464694	6.90	.980712	.65	.483982	7.55	.516018	3
58	.465108	6.90	.980673	.63	.484435	7.53	.515565	2
59	.465522	6.88	.980635	.65	.484887	7.53	.515113	1
60	9.465935		9.980596		9.485339		0.514661	0
	Cos.	D. 1".	Sin.	D. 1".	Cot.	D. 1".	Tan.	M.

M.	Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
0	9.465935	6.88	9.980596	.63	9.485339	7.53	0.514661	60
1	.466348	6.88	.980558	.65	.485791	7.52	.514209	59
2	.466761	6.87	.980519	.65	.486242	7.52	.513758	58
3	.467173	6.87	.980480	.63	.486693	7.50	.513307	57
4	.467585	6.85	.980442	.65	.487143	7.50	.512857	56
5	9.467996	6.85	9.980403	.65	9.487593	7.50	0.512407	55
6	.468407	6.83	.980364	.65	.488043	7.48	.511957	54
7	.468817	6.83	.980325	.65	.488492	7.48	.511508	53
8	.469227	6.83	.980286	.65	.488941	7.48	.511059	52
9	.469637	6.82	.980247	.65	.489390	7.47	.510610	51
10	9.470046	6.82	9.980208	.65	9.489838	7.47	0.510162	50
11	.470455	6.80	.980169	.65	.490286	7.45	.509714	49
12	.470863	6.80	.980130	.65	.490733	7.45	.509267	48
13	.471271	6.80	.980091	.65	.491180	7.45	.508820	47
14	.471679	6.78	.980052	.67	.491627	7.43	.508373	46
15	9.472086	6.77	9.980012	.65	9.492073	7.43	0.507927	45
16	.472492	6.77	.979973	.65	.492519	7.43	.507481	44
17	.472898	6.77	.979934	.65	.492965	7.42	.507035	43
18	.473304	6.77	.979895	.67	.493410	7.40	.506590	42
19	.473710	6.75	.979855	.65	.493854	7.42	.506146	41
20	9.474115	6.73	9.979816	.67	9.494299	7.40	0.505701	40
21	.474519	6.73	.979776	.65	.494743	7.38	.505257	39
22	.474923	6.73	.979737	.67	.495186	7.40	.504814	38
23	.475327	6.72	.979697	.65	.495630	7.38	.504370	37
24	.475730	6.72	.979658	.67	.496073	7.37	.503927	36
25	9.476133	6.72	9.979618	.65	9.496515	7.37	0.503485	35
26	.476536	6.70	.979579	.67	.496957	7.37	.503043	34
27	.476938	6.70	.979539	.67	.497399	7.37	.502601	33
28	.477340	6.68	.979499	.67	.497841	7.35	.502159	32
29	.477741	6.68	.979459	.65	.498282	7.33	.501718	31
30	9.478142	6.67	9.979420	.67	9.498722	7.35	0.501278	30
31	.478542	6.67	.979380	.67	.499163	7.33	.500837	29
32	.478942	6.67	.979340	.67	.499603	7.32	.500397	28
33	.479342	6.65	.979300	.67	.500042	7.32	.499958	27
34	.479741	6.65	.979260	.67	.500481	7.32	.499519	26
35	9.480140	6.65	9.979220	.67	9.500920	7.32	0.499080	25
36	.480539	6.63	.979180	.67	.501359	7.30	.498641	24
37	.480937	6.62	.979140	.67	.501797	7.30	.498203	23
38	.481334	6.62	.979100	.68	.502235	7.28	.497765	22
39	.481731	6.62	.979059	.67	.502672	7.28	.497328	21
40	9.482128	6.62	9.979019	.67	9.503109	7.28	0.496891	20
41	.482525	6.60	.978979	.67	.503546	7.27	.496454	19
42	.482921	6.58	.978939	.68	.503982	7.27	.496018	18
43	.483316	6.60	.978898	.67	.504418	7.27	.495582	17
44	.483712	6.58	.978858	.68	.504854	7.25	.495146	16
45	9.484107	6.57	9.978817	.67	9.505289	7.25	0.494711	15
46	.484501	6.57	.978777	.67	.505724	7.25	.494276	14
47	.484895	6.57	.978737	.68	.506159	7.23	.493841	13
48	.485289	6.55	.978696	.68	.506593	7.23	.493407	12
49	.485682	6.55	.978655	.67	.507027	7.22	.492973	11
50	9.486075	6.53	9.978615	.68	9.507460	7.22	0.492540	10
51	.486467	6.55	.978574	.68	.507893	7.22	.492107	9
52	.486860	6.52	.978533	.67	.508326	7.22	.491674	8
53	.487251	6.53	.978493	.68	.508759	7.20	.491241	7
54	.487643	6.52	.978452	.68	.509191	7.18	.490809	6
55	9.488034	6.50	9.978411	.68	9.509622	7.20	0.490378	5
56	.488424	6.50	.978370	.68	.510054	7.18	.489946	4
57	.488814	6.50	.978329	.68	.510485	7.18	.489515	3
58	.489204	6.48	.978288	.68	.510916	7.17	.489084	2
59	.489593	6.48	.978247	.68	.511346	7.17	.488654	1
60	9.489982		9.978206		9.511776		0.488224	0
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M.

M.	Sin.	D. 1".	Cos.	D. 1".	Tan.	D. 1".	Cot.	
0	9.489982	6.48	9.978206	.68	9.511776	7.17	0.488224	60
1	.490371	6.47	.978165	.68	.512206	7.15	.487794	59
2	.490759	6.47	.978124	.68	.512635	7.15	.487365	58
3	.491147	6.47	.978083	.68	.513064	7.15	.486936	57
4	.491535	6.45	.978042	.68	.513493	7.13	.486507	56
5	9.491922	6.43	9.978001	.70	9.513921	7.13	0.486079	55
6	.492308	6.45	.977959	.68	.514349	7.13	.485651	54
7	.492695	6.43	.977918	.68	.514777	7.12	.485223	53
8	.493081	6.42	.977877	.70	.515204	7.12	.484796	52
[illegible]	.493466	6.42	.977835	.68	.515631	7.10	.484369	51
10	9.493851	6.42	9.977794	.70	9.516057	7.12	0.483943	50
11	.494236	6.42	.977752	.68	.516484	7.10	.483516	49
12	.494621	6.40	.977711	.70	.516910	7.08	.483090	48
13	.495005	6.38	.977669	.68	.517335	7.10	.482665	47
14	.495388	6.40	.977628	.70	.517761	7.08	.482239	46
15	9.495772	6.37	9.977586	.70	9.518186	7.07	0.481814	[illegible]
16	.496154	6.38	.977544	.68	.518610	7.07	.481390	44
17	.496537	6.37	.977503	.70	.519034	7.07	.480966	43
18	.496919	6.37	.977461	.70	.519458	7.07	.480542	42
19	.497301	6.35	.977419	.70	.519882	7.05	.480118	41
20	9.497682	6.37	9.977377	.70	9.520305	7.05	0.479695	40
21	.498064	6.33	.977335	.70	.520728	7.05	.479272	39
22	.498444	6.35	.977293	.70	.521151	7.03	.478849	38
23	.498825	6.32	.977251	.70	.521573	7.03	.478427	37
24	.499204	6.33	.977209	.70	.521995	7.03	.478005	36
25	9.499584	6.32	9.977167	.70	9.522417	7.02	0.477583	35
26	.499963	6.32	.977125	.70	.522838	7.02	.477162	34
27	.500342	6.32	.977083	.70	.523259	7.02	.476741	33
28	.500721	6.30	.977041	.70	.523680	7.00	.476320	32
29	.501099	6.28	.976999	.70	.524100	7.00	.475900	31
30	9.501476	6.30	9.976957	.72	9.524520	7.00	0.475480	30
31	.501854	6.28	.976914	.70	.524940	6.98	.475060	29
32	.502231	6.27	.976872	.70	.525359	6.98	.474641	28
33	.502607	6.28	.976830	.72	.525778	6.98	.474222	27
34	.502984	6.27	.976787	.70	.526197	6.97	.473803	26
35	9.503360	6.25	9.976745	.72	9.526615	6.97	0.473385	[illegible]
36	.503735	6.25	.976702	.70	.527033	6.97	.472967	24
37	.504110	6.25	.976660	.72	.527451	6.95	.472549	23
38	.504485	6.25	.976617	.72	.527868	6.95	.472132	22
39	.504860	6.23	.976574	.70	.528285	6.95	.471715	21
40	9.505234	6.23	9.976532	.72	9.528702	6.95	0.471298	20
41	.505608	6.22	.976489	.72	.529119	6.93	.470881	19
42	.505981	6.22	.976446	.70	.529535	6.93	.470465	18
43	.506354	6.22	.976404	.72	.529951	6.92	.470049	17
44	.506727	6.20	.976361	.72	.530366	6.92	.469634	16
45	9.507099	6.20	9.976318	.72	9.530781	6.92	0.469219	15
46	.507471	6.20	.976275	.72	.531196	6.92	.468804	14
47	.507843	6.18	.976232	.72	.531611	6.90	.468389	13
48	.508214	6.18	.976189	.72	.532025	6.90	.467975	12
49	.508585	6.18	.976146	.72	.532439	6.90	.467561	11
50	9.508956	6.17	9.976103	.72	9.532853	6.88	0.467147	10
51	.509326	6.17	.976060	.72	.533266	6.88	.466734	9
52	.509696	6.15	.976017	.72	.533679	6.88	.466321	8
53	.510065	6.15	.975974	.73	.534092	6.87	.465908	7
54	.510434	6.15	.975930	.72	.534504	6.87	.465496	6
55	9.510803	6.15	9.975887	.72	9.534916	6.87	0.465084	5
56	.511172	6.13	.975844	.73	.535328	6.85	.464672	4
57	.511540	6.12	.975800	.72	.535739	6.85	.464261	3
58	.511907	6.13	.975757	.72	.536150	6.85	.463850	2
59	.512275	6.12	.975714	.73	.536561	6.85	.463439	1
60	9.512642		9.975670		9.536972		0.463028	0
	Cos.	D. 1".	Sin.	D. 1".	Cot.	D. 1".	Tan.	M

M.	Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
0	9.512642	6.12	9.975670	.72	9.536972	6.83	0.463028	60
1	.513009	6.10	.975627	.73	.537382	6.83	.462618	59
2	.513375	6.10	.975583	.73	.537792	6.83	.462208	58
3	.513741	6.10	.975539	.72	.538202	6.82	.461798	57
4	.514107	6.08	.975496	.73	.538611	6.82	.461389	56
5	9.514472	6.08	9.975452	.73	9.539020	6.82	0.460980	55
6	.514837	6.08	.975408	.72	.539429	6.80	.460571	54
7	.515202	6.07	.975365	.73	.539837	6.80	.460163	53
8	.515566	6.07	.975321	.73	.540245	6.80	.459755	52
9	.515930	6.07	.975277	.73	.540653	6.80	.459347	51
10	9.516294	6.05	9.975233	.73	9.541061	6.78	0.458939	50
11	.516657	6.05	.975189	.73	.541468	6.78	.458532	49
12	.517020	6.03	.975145	.73	.541875	6.77	.458125	48
13	.517382	6.05	.975101	.73	.542281	6.78	.457719	47
14	.517745	6.03	.975057	.73	.542688	6.77	.457312	46
15	9.518107	6.02	9.975013	.73	9.543094	6.75	0.456906	45
16	.518468	6.02	.974969	.73	.543499	6.77	.456501	44
17	.518829	6.02	.974925	.75	.543905	6.75	.456095	43
18	.519190	6.02	.974880	.73	.544310	6.75	.455690	42
19	.519551	6.00	.974836	.73	.544715	6.73	.455285	41
20	9.519911	6.00	9.974792	.73	9.545119	6.75	0.454881	40
21	.520271	6.00	.974748	.75	.545524	6.73	.454476	39
22	.520631	5.98	.974703	.73	.545928	6.72	.454072	38
23	.520990	5.98	.974659	.75	.546331	6.73	.453669	37
24	.521349	5.97	.974614	.73	.546735	6.72	.453265	36
25	9.521707	5.98	9.974570	.75	9.547138	6.70	0.452862	35
26	.522066	5.97	.974525	.73	.547540	6.72	.452460	34
27	.522424	5.95	.974481	.75	.547943	6.70	.452057	33
28	.522781	5.95	.974436	.75	.548345	6.70	.451655	32
29	.523138	5.95	.974391	.73	.548747	6.70	.451253	31
30	9.523495	5.95	9.974347	.75	9.549149	6.68	0.450851	30
31	.523852	5.93	.974302	.75	.549550	6.68	.450450	29
32	.524208	5.93	.974257	.75	.549951	6.68	.450049	28
33	.524564	5.93	.974212	.75	.550352	6.67	.449648	27
34	.524920	5.92	.974167	.75	.550752	6.68	.449248	26
35	9.525275	5.92	9.974122	.75	9.551153	6.65	0.448847	25
36	.525630	5.90	.974077	.75	.551552	6.67	.448448	24
37	.525984	5.92	.974032	.75	.551952	6.65	.448048	23
38	.526339	5.90	.973987	.75	.552351	6.65	.447649	22
39	.526693	5.88	.973942	.75	.552750	6.65	.447250	21
40	9.527046	5.90	9.973897	.75	9.553149	6.65	0.446851	20
41	.527400	5.88	.973852	.75	.553548	6.63	.446452	19
42	.527753	5.87	.973807	.77	.553946	6.63	.446054	18
43	.528105	5.88	.973761	.75	.554344	6.62	.445656	17
44	.528458	5.87	.973716	.75	.554741	6.63	.445259	16
45	9.528810	5.85	9.973671	.77	9.555139	6.62	0.444861	15
46	.529161	5.87	.973625	.75	.555536	6.62	.444464	14
47	.529513	5.85	.973580	.75	.555933	6.60	.444067	13
48	.529864	5.85	.973535	.77	.556329	6.60	.443671	12
49	.530215	5.83	.973489	.75	.556725	6.60	.443275	11
50	9.530565	5.83	9.973444	.77	9.557121	6.60	0.442879	10
51	.530915	5.83	.973398	.77	.557517	6.60	.442483	9
52	.531265	5.82	.973352	.75	.557913	6.58	.442087	8
53	.531614	5.82	.973307	.77	.558308	6.58	.441692	7
54	.531963	5.82	.973261	.77	.558703	6.57	.441297	6
55	9.532312	5.82	9.973215	.77	9.559097	6.57	0.440903	5
56	.532661	5.80	.973169	.75	.559491	6.57	.440509	4
57	.533009	5.80	.973124	.77	.559885	6.57	.440115	3
58	.533357	5.78	.973078	.77	.560279	6.57	.439721	2
59	.533704	5.80	.973032	.77	.560673	6.55	.439327	1
60	9.534052		9.972986		9.561066		0.438934	0
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M.

M.	Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
0	9.534052	5.78	9.972986	.77	9.561066	6.55	0.438934	60
1	.534399	5.77	.972940	.77	.561459	6.53	.438541	59
2	.534745	5.78	.972894	.77	.561851	6.55	.438149	58
3	.535092	5.77	.972848	.77	.562244	6.53	.437756	57
4	.535438	5.75	.972802	.78	.562636	6.53	.437364	56
5	9.535783	5.77	9.972755	.77	9.563028	6.52	0.436972	55
6	.536129	5.75	.972709	.77	.563419	6.53	.436581	54
7	.536474	5.73	.972663	.77	.563811	6.52	.436189	53
8	.536818	5.75	.972617	.78	.564202	6.52	.435798	52
9	.537163	5.73	.972570	.77	.564593	6.50	.435407	51
10	9.537507	5.73	9.972524	.77	9.564983	6.50	0.435017	50
11	.537851	5.72	.972478	.78	.565373	6.50	.434627	49
12	.538194	5.73	.972431	.77	.565763	6.50	.434237	48
13	.538538	5.70	.972385	.78	.566153	6.48	.433847	47
14	.538880	5.72	.972338	.78	.566542	6.50	.433458	46
15	9.539223	5.70	9.972291	.77	9.566932	6.47	0.433068	45
16	.539565	5.70	.972245	.78	.567320	6.48	.432680	44
17	.539907	5.70	.972198	.78	.567709	6.48	.432291	43
18	.540249	5.68	.972151	.77	.568098	6.47	.431902	42
19	.540590	5.68	.972105	.78	.568486	6.45	.431514	41
20	9.540931	5.68	9.972058	.78	9.568873	6.47	0.431127	40
21	.541272	5.68	.972011	.78	.569261	6.45	.430739	39
22	.541613	5.67	.971964	.78	.569648	6.45	.430352	38
23	.541953	5.67	.971917	.78	.570035	6.45	.429965	37
24	.542293	5.65	.971870	.78	.570422	6.45	.429578	36
25	9.542632	5.65	9.971823	.78	9.570809	6.43	0.429191	35
26	.542971	5.65	.971776	.78	.571195	6.43	.428805	34
27	.543310	5.65	.971729	.78	.571581	6.43	.428419	33
28	.543649	5.63	.971682	.78	.571967	6.42	.428033	32
29	.543987	5.63	.971635	.78	.572352	6.43	.427648	31
30	9.544325	5.63	9.971588	.80	9.572738	6.42	0.427262	30
31	.544663	5.62	.971540	.78	.573123	6.40	.426877	29
32	.545000	5.63	.971493	.78	.573507	6.42	.426493	28
33	.545338	5.60	.971446	.80	.573892	6.40	.426108	27
34	.545674	5.62	.971398	.78	.574276	6.40	.425724	26
35	9.546011	5.60	9.971351	.80	9.574660	6.40	0.425340	25
36	.546347	5.60	.971303	.78	.575044	6.38	.424956	24
37	.546683	5.60	.971256	.80	.575427	6.38	.424573	23
38	.547019	5.58	.971208	.78	.575810	6.38	.424190	22
39	.547354	5.58	.971161	.80	.576193	6.38	.423807	21
40	9.547689	5.58	9.971113	.78	9.576576	6.38	0.423424	20
41	.548024	5.58	.971066	.80	.576959	6.37	.423041	19
42	.548359	5.57	.971018	.80	.577341	6.37	.422659	18
43	.548693	5.57	.970970	.80	.577723	6.35	.422277	17
44	.549027	5.55	.970922	.80	.578104	6.37	.421896	16
45	9.549360	5.55	9.970874	.78	9.578486	6.35	0.421514	15
46	.549693	5.55	.970827	.80	.578867	6.35	.421133	14
47	.550026	5.55	.970779	.80	.579248	6.35	.420752	13
48	.550359	5.55	.970731	.80	.579629	6.33	.420371	12
49	.550692	5.53	.970683	.80	.580009	6.33	.419991	11
50	9.551024	5.53	9.970635	.82	9.580389	6.33	0.419611	10
51	.551356	5.52	.970586	.80	.580769	6.33	.419231	9
52	.551687	5.52	.970538	.80	.581149	6.32	.418851	8
53	.552018	5.52	.970490	.80	.581528	6.32	.418472	7
54	.552349	5.52	.970442	.80	.581907	6.32	.418093	6
55	9.552680	5.50	9.970394	.82	9.582286	6.32	0.417714	5
56	.553010	5.52	.970345	.80	.582665	6.32	.417335	4
57	.553341	5.48	.970297	.80	.583044	6.30	.416956	3
58	.553670	5.50	.970249	.82	.583422	6.30	.416578	2
59	.554000	5.48	.970200	.80	.583800	6.28	.416200	1
60	9.554329		9.970152		9.584177		0.415823	0
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M.

M.	Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
0	9.554329	5.48	9.970152	.82	9.584177	6.30	0.415823	60
1	.554658	5.48	.970103	.80	.584555	6.28	.415445	59
2	.554987	5.47	.970055	.82	.584932	6.28	.415068	58
3	.555315	5.47	.970006	.82	.585309	6.28	.414691	57
4	.555643	5.47	.969957	.80	.585686	6.27	.414314	56
5	9.555971	5.47	9.969909	.82	9.586062	6.28	0.413938	55
6	.556299	5.45	.969860	.82	.586439	6.27	.413561	54
7	.556626	5.45	.969811	.82	.586815	6.25	.413185	53
8	.556953	5.45	.969762	.80	.587190	6.27	.412810	52
9	.557280	5.43	.969714	.82	.587566	6.25	.412434	51
10	9.557606	5.43	9.969665	.82	9.587941	6.25	0.412059	50
11	.557932	5.43	.969616	.82	.588316	6.25	.411684	49
12	.558258	5.42	.969567	.82	.588691	6.25	.411309	48
13	.558583	5.43	.969518	.82	.589066	6.23	.410934	47
14	.558909	5.42	.969469	.82	.589440	6.23	.410560	46
15	9.559234	5.40	9.969420	.83	9.589814	6.23	0.410186	45
16	.559558	5.42	.969370	.82	.590188	6.23	.409812	44
17	.559883	5.40	.969321	.82	.590562	6.22	.409438	43
18	.560207	5.40	.969272	.82	.590935	6.22	.409065	42
19	.560531	5.40	.969223	.83	.591308	6.22	.408692	41
20	9.560855	5.38	9.969173	.82	9.591681	6.22	0.408319	40
21	.561178	5.38	.969124	.82	.592054	6.20	.407946	39
22	.561501	5.38	.969075	.83	.592426	6.22	.407574	38
23	.561824	5.37	.969025	.82	.592799	6.20	.407201	37
24	.562146	5.37	.968976	.83	.593171	6.18	.406829	36
25	9.562468	5.37	9.968926	.82	9.593542	6.20	0.406458	35
26	.562790	5.37	.968877	.83	.593914	6.18	.406086	34
27	.563112	5.35	.968827	.83	.594285	6.18	.405715	33
28	.563433	5.37	.968777	.82	.594656	6.18	.405344	32
29	.563755	5.33	.968728	.83	.595027	6.18	.404973	31
30	9.564075	5.35	9.968678	.83	9.595398	6.17	0.404602	30
31	.564396	5.33	.968628	.83	.595768	6.17	.404232	29
32	.564716	5.33	.968578	.83	.596138	6.17	.403862	28
33	.565036	5.33	.968528	.82	.596508	6.17	.403492	27
34	.565356	5.33	.968479	.83	.596878	6.15	.403122	26
35	9.565676	5.32	9.968429	.83	9.597247	6.15	0.402753	25
36	.565995	5.32	.968379	.83	.597616	6.15	.402384	24
37	.566314	5.30	.968329	.85	.597985	6.15	.402015	23
38	.566632	5.32	.968278	.83	.598354	6.13	.401646	22
39	.566951	5.30	.968228	.83	.598722	6.15	.401278	21
40	9.567269	5.30	9.968178	.83	9.599091	6.13	0.400909	20
41	.567587	5.28	.968128	.83	.599459	6.13	.400541	19
42	.567904	5.30	.968078	.85	.599827	6.12	.400173	18
43	.568222	5.28	.968027	.83	.600194	6.13	.399806	17
44	.568539	5.28	.967977	.83	.600562	6.12	.399438	16
45	9.568856	5.27	9.967927	.85	9.600929	6.12	0.399071	15
46	.569172	5.27	.967876	.83	.601296	6.12	.398704	14
47	.569488	5.27	.967826	.85	.601663	6.10	.398337	13
48	.569804	5.27	.967775	.83	.602029	6.10	.397971	12
49	.570120	5.25	.967725	.85	.602395	6.10	.397605	11
50	9.570435	5.27	9.967674	.83	9.602761	6.10	0.397239	10
51	.570751	5.25	.967624	.85	.603127	6.10	.396873	9
52	.571066	5.23	.967573	.85	.603493	6.08	.396507	8
53	.571380	5.25	.967522	.85	.603858	6.08	.396142	7
54	.571695	5.23	.967471	.83	.604223	6.08	.395777	6
55	9.572009	5.23	9.967421	.85	9.604588	6.08	0.395412	5
56	.572323	5.22	.967370	.85	.604953	6.07	.395047	4
57	.572636	5.23	.967319	.85	.605317	6.08	.394683	3
58	.572950	5.22	.967268	.85	.605682	6.07	.394318	2
59	.573263	5.20	.967217	.85	.606046	6.07	.393954	1
60	9.573575		9.967166		9.606410		0.393590	0
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M.

Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
9.573575	5.22	9.967166	.85	9.606410	6.05	0.393590	60
.573888	5.20	.967115	.85	.606773	6.07	.393227	59
.574200	5.20	.967064	.85	.607137	6.05	.392863	58
.574512	5.20	.967013	.87	.607500	6.05	.392500	57
.574824	5.20	.966961	.85	.607863	6.03	.392137	56
9.575136	5.18	9.966910	.85	9.608225	6.05	0.391775	55
.575447	5.18	.966859	.85	.608588	6.03	.391412	54
.575758	5.18	.966808	.87	.608950	6.03	.391050	53
.576069	5.17	.966756	.85	.609312	6.03	.390688	52
.576379	5.17	.966705	.87	.609674	6.03	.390326	51
9.576689	5.17	9.966653	.85	9.610036	6.02	0.389964	50
.576999	5.17	.966602	.87	.610397	6.03	.389603	49
.577309	5.15	.966550	.85	.610759	6.02	.389241	48
.577618	5.15	.966499	.87	.611120	6.00	.388880	47
.577927	5.15	.966447	.87	.611480	6.02	.388520	46
9.578236	5.15	9.966395	.85	9.611841	6.00	0.388159	45
.578545	5.13	.966344	.87	.612201	6.00	.387799	44
.578853	5.15	.966292	.87	.612561	6.00	.387439	43
.579162	5.13	.966240	.87	.612921	6.00	.387079	42
.579470	5.12	.966188	.87	.613281	6.00	.386719	41
9.579777	5.13	9.966136	.85	9.613641	5.98	0.386359	40
.580085	5.12	.966085	.87	.614000	5.98	.386000	39
.580392	5.12	.966033	.87	.614359	5.98	.385641	38
.580699	5.10	.965981	.87	.614718	5.98	.385282	37
.581005	5.12	.965929	.88	.615077	5.97	.384923	36
9.581312	5.10	9.965876	.87	9.615435	5.97	0.384565	35
.581618	5.10	.965824	.87	.615793	5.97	.384207	34
.581924	5.08	.965772	.87	.616151	5.97	.383849	33
.582229	5.10	.965720	.87	.616509	5.97	.383491	32
.582535	5.08	.965668	.88	.616867	5.95	.383133	31
9.582840	5.08	9.965615	.87	9.617224	5.97	0.382776	30
.583145	5.07	.965563	.87	.617582	5.95	.382418	29
.583449	5.08	.965511	.88	.617939	5.93	.382061	28
.583754	5.07	.965458	.87	.618295	5.95	.381705	27
.584058	5.05	.965406	.88	.618652	5.93	.381348	26
9.584361	5.07	9.965353	.87	9.619008	5.93	0.380992	25
.584665	5.05	.965301	.88	.619364	5.93	.380636	24
.584968	5.07	.965248	.88	.619720	5.93	.380280	23
.585272	5.03	.965195	.87	.620076	5.93	.379924	22
.585574	5.05	.965143	.88	.620432	5.92	.379568	21
9.585877	5.03	9.965090	.88	9.620787	5.92	0.379213	20
.586179	5.05	.965037	.88	.621142	5.92	.378858	19
.586482	5.02	.964984	.88	.621497	5.92	.378503	18
.586783	5.03	.964931	.87	.621852	5.92	.378148	17
.587085	5.02	.964879	.88	.622207	5.90	.377793	16
9.587386	5.03	9.964826	.88	9.622561	5.90	0.377439	15
.587688	5.02	.964773	.88	.622915	5.90	.377085	14
.587989	5.00	.964720	.90	.623269	5.90	.376731	13
.588289	5.02	.964666	.88	.623623	5.88	.376377	12
.588590	5.00	.964613	.88	.623976	5.90	.376024	11
9.588890	5.00	9.964560	.88	9.624330	5.88	0.375670	10
.589190	4.98	.964507	.88	.624683	5.88	.375317	9
.589489	5.00	.964454	.90	.625036	5.87	.374964	8
.589789	4.98	.964400	.88	.625388	5.88	.374612	7
.590088	4.98	.964347	.88	.625741	5.87	.374259	6
9.590387	4.98	9.964294	.90	9.626093	5.87	0.373907	5
.590686	4.97	.964240	.88	.626445	5.87	.373555	4
.590984	4.97	.964187	.90	.626797	5.87	.373203	3
.591282	4.97	.964133	.88	.627149	5.87	.372851	2
.591580	4.97	.964080	.90	.627501	5.85	.372499	1
9.591878		9.964026		9.627852		0.372148	0
Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M.

M.	Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
0	9.591878	4.97	9.964026	.90	9.627852	5.85	0.372148	60
1	.592176	4.95	.963972	.88	.628203	5.85	.371797	59
2	.592473	4.95	.963919	.90	.628554	5.85	.371446	58
3	.592770	4.95	.963865	.90	.628905	5.83	.371095	57
4	.593067	4.93	.963811	.90	.629255	5.85	.370745	56
5	9.593363	4.93	9.963757	.88	9.629606	5.83	0.370394	55
6	.593659	4.93	.963704	.90	.629956	5.83	.370044	54
7	.593955	4.93	.963650	.90	.630306	5.83	.369694	53
8	.594251	4.93	.963596	.90	.630656	5.82	.369344	52
9	.594547	4.92	.963542	.90	.631005	5.83	.368995	51
10	9.594842	4.92	9.963488	.90	9.631355	5.82	0.368645	50
11	.595137	4.92	.963434	.92	.631704	5.82	.368296	49
12	.595432	4.92	.963379	.90	.632053	5.82	.367947	48
13	.595727	4.90	.963325	.90	.632402	5.80	.367598	47
14	.596021	4.90	.963271	.90	.632750	5.82	.367250	46
15	9.596315	4.90	9.963217	.90	9.633099	5.80	0.366901	45
16	.596609	4.90	.963163	.92	.633447	5.80	.366553	44
17	.596903	4.88	.963108	.90	.633795	5.80	.366205	43
18	.597196	4.90	.963054	.92	.634143	5.78	.365857	42
19	.597490	4.88	.962999	.90	.634490	5.80	.365510	41
20	9.597783	4.87	9.962945	.92	9.634838	5.78	0.365162	40
21	.598075	4.88	.962890	.90	.635185	5.78	.364815	39
22	.598368	4.87	.962836	.92	.635532	5.78	.364468	38
23	.598660	4.87	.962781	.90	.635879	5.78	.364121	37
24	.598952	4.87	.962727	.92	.636226	5.77	.363774	36
25	9.599244	4.87	9.962672	.92	9.636572	5.78	0.363428	35
26	.599536	4.85	.962617	.92	.636919	5.77	.363081	34
27	.599827	4.85	.962562	.90	.637265	5.77	.362735	33
28	.600118	4.85	.962508	.92	.637611	5.75	.362389	32
29	.600409	4.85	.962453	.92	.637956	5.77	.362044	31
30	9.600700	4.83	9.962398	.92	9.638302	5.75	0.361698	30
31	.600990	4.83	.962343	.92	.638647	5.75	.361353	29
32	.601280	4.83	.962288	.92	.638992	5.75	.361008	28
33	.601570	4.83	.962233	.92	.639337	5.75	.360663	27
34	.601860	4.83	.962178	.92	.639682	5.75	.360318	26
35	9.602150	4.82	9.962123	.93	9.640027	5.73	0.359973	25
36	.602439	4.82	.962067	.92	.640371	5.75	.359629	24
37	.602728	4.82	.962012	.92	.640716	5.73	.359284	23
38	.603017	4.80	.961957	.92	.641060	5.73	.358940	22
39	.603305	4.82	.961902	.93	.641404	5.72	.358596	21
40	9.603594	4.80	9.961846	.92	9.641747	5.73	0.358253	20
41	.603882	4.80	.961791	.93	.642091	5.72	.357909	19
42	.604170	4.78	.961735	.92	.642434	5.72	.357566	18
43	.604457	4.80	.961680	.93	.642777	5.72	.357223	17
44	.604745	4.78	.961624	.92	.643120	5.72	.356880	16
45	9.605032	4.78	9.961569	.93	9.643463	5.72	0.356537	15
46	.605319	4.78	.961513	.92	.643806	5.70	.356194	14
47	.605606	4.77	.961458	.93	.644148	5.70	.355852	13
48	.605892	4.78	.961402	.93	.644490	5.70	.355510	12
49	.606179	4.77	.961346	.93	.644832	5.70	.355168	11
50	9.606465	4.77	9.961290	.92	9.645174	5.70	0.354826	10
51	.606751	4.75	.961235	.93	.645516	5.68	.354484	9
52	.607036	4.77	.961179	.93	.645857	5.70	.354143	8
53	.607322	4.75	.961123	.93	.646199	5.68	.353801	7
54	.607607	4.75	.961067	.93	.646540	5.68	.353460	6
55	9.607892	4.75	9.961011	.93	9.646881	5.68	0.353119	5
56	.608177	4.73	.960955	.93	.647222	5.67	.352778	4
57	.608461	4.73	.960899	.93	.647562	5.68	.352438	3
58	.608745	4.73	.960843	.95	.647903	5.67	.352097	2
59	.609029	4.73	.960786	.93	.648243	5.67	.351757	1
60	9.609313		9.960730		9.648583		0.351417	0
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M.

M.	Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
0	9.609313	4.73	9.960730	.93	9.648583	5.67	0.351417	60
1	.609597	4.72	.960674	.93	.648923	5.67	.351077	59
2	.609880	4.73	.960618	.95	.649263	5.65	.350737	58
3	.610164	4.72	.960561	.93	.649602	5.67	.350398	57
4	.610447	4.70	.960505	.95	.649942	5.65	.350058	56
5	9.610729	4.72	9.960448	.93	9.650281	5.65	0.349719	55
6	.611012	4.70	.960392	.95	.650620	5.65	.349380	54
7	.611294	4.70	.960335	.93	.650959	5.63	.349041	53
8	.611576	4.70	.960279	.95	.651297	5.65	.348703	52
9	.611858	4.70	.960222	.95	.651636	5.63	.348364	51
10	9.612140	4.68	9.960165	.93	9.651974	5.63	0.348026	50
11	.612421	4.68	.960109	.95	.652312	5.63	.347688	49
12	.612702	4.68	.960052	.95	.652650	5.63	.347350	48
13	.612983	4.68	.959995	.95	.652988	5.63	.347012	47
14	.613264	4.68	.959938	.93	.653326	5.62	.346674	46
15	9.613545	4.67	9.959882	.95	9.653663	5.62	0.346337	45
16	.613825	4.67	.959825	.95	.654000	5.62	.346000	44
17	.614105	4.67	.959768	.95	.654337	5.62	.345663	43
18	.614385	4.67	.959711	.95	.654674	5.62	.345326	42
19	.614665	4.65	.959654	.97	.655011	5.62	.344989	41
20	9.614944	4.65	9.959596	.95	9.655348	5.60	0.344652	40
21	.615223	4.65	.959539	.95	.655684	5.60	.344316	39
22	.615502	4.65	.959482	.95	.656020	5.60	.343980	38
23	.615781	4.65	.959425	.95	.656356	5.60	.343644	37
24	.616060	4.63	.959368	.97	.656692	5.60	.343308	36
25	9.616338	4.63	9.959310	.95	9.657028	5.60	0.342972	35
26	.616616	4.63	.959253	.97	.657364	5.58	.342636	34
27	.616894	4.63	.959195	.95	.657699	5.58	.342301	33
28	.617172	4.63	.959138	.97	.658034	5.58	.341966	32
29	.617450	4.62	.959080	.95	.658369	5.58	.341631	31
30	9.617727	4.62	9.959023	.97	9.658704	5.58	0.341296	30
31	.618004	4.62	.958965	.95	.659039	5.57	.340961	29
32	.618281	4.62	.958908	.97	.659373	5.58	.340627	28
33	.618558	4.60	.958850	.97	.659708	5.57	.340292	27
34	.618834	4.60	.958792	.97	.660042	5.57	.339958	26
35	9.619110	4.60	9.958734	.95	9.660376	5.57	0.339624	25
36	.619386	4.60	.958677	.97	.660710	5.55	.339290	24
37	.619662	4.60	.958619	.97	.661043	5.57	.338957	23
38	.619938	4.58	.958561	.97	.661377	5.55	.338623	22
39	.620213	4.58	.958503	.97	.661710	5.55	.338290	21
40	9.620488	4.58	9.958445	.97	9.662043	5.55	0.337957	20
41	.620763	4.58	.958387	.97	.662376	5.55	.337624	19
42	.621038	4.58	.958329	.97	.662709	5.55	.337291	18
43	.621313	4.57	.958271	.97	.663042	5.55	.336958	17
44	.621587	4.57	.958213	.98	.663375	5.53	.336625	16
45	9.621861	4.57	9.958154	.97	9.663707	5.53	0.336293	15
46	.622135	4.57	.958096	.97	.664039	5.53	.335961	14
47	.622409	4.55	.958038	.98	.664371	5.53	.335629	13
48	.622682	4.57	.957979	.97	.664703	5.53	.335297	12
49	.622956	4.55	.957921	.97	.665035	5.52	.334965	11
50	9.623229	4.55	9.957863	.98	9.665366	5.53	0.334634	10
51	.623502	4.53	.957804	.97	.665698	5.52	.334302	9
52	.623774	4.55	.957746	.98	.666029	5.52	.333971	8
53	.624047	4.53	.957687	.98	.666360	5.52	.333640	7
54	.624319	4.53	.957628	.97	.666691	5.50	.333309	6
55	9.624591	4.53	9.957570	.98	9.667021	5.52	0.332979	5
56	.624863	4.53	.957511	.98	.667352	5.50	.332648	4
57	.625135	4.52	.957452	.98	.667682	5.52	.332318	3
58	.625406	4.52	.957393	.97	.668013	5.50	.331987	2
59	.625677	4.52	.957335	.98	.668343	5.50	.331657	1
60	9.625948		9.957276		9.668673		0.331327	0
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M.

M.	Sin.	D. 1".	Cos.	D. 1".	Tan.	D. 1".	Cot.	M.
0	9.625948	[illegible]	9.957276	.98	9.668673	5.48	0.331327	60
1	.626219	4.52	.957217	.98	.669002	5.50	.330998	59
2	.626490	4.50	.957158	.98	.669332	5.48	.330668	58
3	.626760	4.50	.957099	.98	.669661	5.50	.330339	57
4	.627030	4.50	.957040	.98	.669991	5.48	.330009	56
5	9.627300	4.50	9.956981	1.00	9.670320	5.48	0.329680	55
6	.627570	4.50	.956921	.98	.670649	5.47	.329351	54
7	.627840	4.48	.956862	.98	.670977	5.48	.329023	53
8	.628109	4.48	.956803	.98	.671306	5.48	.328694	52
9	.628378	4.48	.956744	1.00	.671635	5.47	.328365	51
10	9.628647	4.48	9.956684	.98	9.671963	5.47	0.328037	50
11	.628916	4.48	.956625	.98	.672291	5.47	.327709	49
12	.629185	4.47	.956566	1.00	.672619	5.47	.327381	48
13	.629453	4.47	.956506	.98	.672947	5.45	.327053	47
14	.629721	4.47	.956447	1.00	.673274	5.47	.326726	46
15	9.629989	4.47	9.956387	1.00	9.673602	5.45	0.326398	45
16	.630257	4.45	.956327	.98	.673929	5.47	.326071	44
17	.630524	4.47	.956268	1.00	.674257	5.45	.325743	43
18	.630792	4.45	.956208	1.00	.674584	5.45	.325416	42
19	.631059	4.45	.956148	.98	.674911	5.43	.325089	41
20	9.631326	4.45	9.956089	1.00	9.675237	5.45	0.324763	40
21	.631593	4.43	.956029	1.00	.675564	5.43	.324436	39
22	.631859	4.43	.955969	1.00	.675890	5.45	.324110	38
23	.632125	4.45	.955909	1.00	.676217	5.43	.323783	37
24	.632392	4.43	.955849	1.00	.676543	5.43	.323457	36
25	9.632658	4.42	9.955789	1.00	9.676869	5.42	0.323131	35
26	.632923	4.43	.955729	1.00	.677194	5.43	.322806	34
27	.633189	4.42	.955669	1.00	.677520	5.43	.322480	33
28	.633454	4.42	.955609	1.02	.677846	5.42	.322154	32
29	.633719	4.42	.955548	1.00	.678171	5.42	.321829	31
30	9.633984	4.42	9.955488	1.00	9.678496	5.42	0.321504	30
31	.634249	4.42	.955428	1.00	.678821	5.42	.321179	29
32	.634514	4.40	.955368	1.02	.679146	5.42	.320854	28
33	.634778	4.40	.955307	1.00	.679471	5.40	.320529	27
34	.635042	4.40	.955247	1.02	.679795	5.42	.320205	26
35	9.635306	4.40	9.955186	1.00	9.680120	5.40	0.319880	25
36	.635570	4.40	.955126	1.02	.680444	5.40	.319556	24
37	.635834	4.38	.955065	1.00	.680768	5.40	.319232	23
38	.636097	4.38	.955005	1.02	.681092	5.40	.318908	22
39	.636360	4.38	.954944	1.02	.681416	5.40	.318584	21
40	9.636623	4.38	9.954883	1.00	9.681740	5.38	0.318260	20
41	.636886	4.37	.954823	1.02	.682063	5.40	.317937	19
42	.637148	4.38	.954762	1.02	.682387	5.38	.317613	18
43	.637411	4.37	.954701	1.02	.682710	5.38	.317290	17
44	.637673	4.37	.954640	1.02	.683033	5.38	.316967	16
45	9.637935	4.37	9.954579	1.02	9.683356	5.38	0.316644	15
46	.638197	4.35	.954518	1.02	.683679	5.37	.316321	14
47	.638458	4.37	.954457	1.02	.684001	5.38	.315999	13
48	.638720	4.35	.954396	1.02	.684324	5.37	.315676	12
49	.638981	4.35	.954335	1.02	.684646	5.37	.315354	11
50	9.639242	4.35	9.954274	1.02	9.684968	5.37	0.315032	10
51	.639503	4.35	.954213	1.02	.685290	5.37	.314710	9
52	.639764	4.33	.954152	1.03	.685612	5.37	.314388	8
53	.640024	4.33	.954090	1.02	.685934	5.35	.314066	7
54	.640284	4.33	.954029	1.02	.686255	5.37	.313745	6
55	9.640544	4.33	9.953968	1.03	9.686577	5.35	0.313423	5
56	.640804	4.33	.953906	1.02	.686898	5.35	.313102	4
57	.641064	4.33	.953845	1.03	.687219	5.35	.312781	3
58	.641324	4.32	.953783	1.02	.687540	5.35	.312460	2
59	.641583	4.32	.953722	1.03	.687861	5.35	.312139	1
60	9.641842		9.953660		9.688182		0.311818	0
	Cos.	D. 1".	Sin.	D. 1".	Cot.	D. 1".	Tan.	M.

M.	Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
0	9.641842	4.32	9.953660	1.02	9.688182	5.33	0.311818	60
1	.642101	4.32	.953599	1.03	.688502	5.35	.311498	59
2	.642360	4.30	.953537	1.03	.688823	5.33	.311177	58
3	.642618	4.32	.953475	1.03	.689143	5.33	.310857	57
4	.642877	4.30	.953413	1.02	.689463	5.33	.310537	56
5	9.643135	4.30	9.953352	1.03	9.689783	5.33	0.310217	55
6	.643393	4.28	.953290	1.03	.690103	5.33	.309897	54
7	.643650	4.30	.953228	1.03	.690423	5.32	.309577	53
8	.643908	4.28	.953166	1.03	.690742	5.33	.309258	52
9	.644165	4.30	.953104	1.03	.691062	5.32	.308938	51
10	9.644423	4.28	9.953042	1.03	9.691381	5.32	0.308619	50
11	.644680	4.27	.952980	1.03	.691700	5.32	.308300	49
12	.644936	4.28	.952918	1.05	.692019	5.32	.307981	48
13	.645193	4.28	.952855	1.03	.692338	5.30	.307662	47
14	.645450	4.27	.952793	1.03	.692656	5.32	.307344	46
15	9.645706	4.27	9.952731	1.03	9.692975	5.30	0.307025	45
16	.645962	4.27	.952669	1.05	.693293	5.32	.306707	44
17	.646218	4.27	.952606	1.03	.693612	5.30	.306388	43
18	.646474	4.25	.952544	1.05	.693930	5.30	.306070	42
19	.646729	4.25	.952481	1.03	.694248	5.30	.305752	41
20	9.646984	4.27	9.952419	1.05	9.694566	5.28	0.305434	40
21	.647240	4.23	.952356	1.03	.694883	5.30	.305117	39
22	.647494	4.25	.952294	1.05	.695201	5.28	.304799	38
23	.647749	4.25	.952231	1.05	.695518	5.30	.304482	37
24	.648004	4.23	.952168	1.03	.695836	5.28	.304164	36
25	9.648258	4.23	9.952106	1.05	9.696[illegible]53	5.28	0.303847	35
26	.648512	4.23	.952043	1.05	.696470	5.28	.303530	34
27	.648766	4.23	.951980	1.05	.696787	5.27	.303213	33
28	.649020	4.23	.951917	1.05	.697103	5.28	.302897	32
29	.649274	4.22	.951854	1.05	.697420	5.27	.302580	31
30	9.649527	4.23	9.951791	1.05	9.697736	5.28	0.302264	30
31	.649781	4.22	.951728	1.05	.698053	5.27	.301947	29
32	.650034	4.22	.951665	1.05	.698369	5.27	.301631	28
33	.650287	4.20	.951602	1.05	.698685	5.27	.301315	27
34	.650539	4.22	.951539	1.05	.699001	5.25	.300999	26
35	9.650792	4.20	9.951476	1.07	9.699316	5.27	0.300684	25
36	.651044	4.22	.951412	1.05	.699632	5.25	.300368	24
37	.651297	4.20	.951349	1.05	.699947	5.27	.300053	23
38	.651549	4.18	.951286	1.07	.700263	5.25	.299737	22
39	.651800	4.20	.951222	1.05	.700578	5.25	.299422	21
40	9.652052	4.20	9.951159	1.05	9.700893	5.25	0.299107	20
41	.652304	4.18	.951096	1.07	.701208	5.25	.298792	19
42	.652555	4.18	.951032	1.07	.701523	5.23	.298477	18
43	.652806	4.18	.950968	1.05	.701837	5.25	.298163	17
44	.653057	4.18	.950905	1.07	.702152	5.23	.297848	16
45	9.653308	4.17	9.950841	1.05	9.702466	5.25	0.297534	15
46	.653558	4.17	.950778	1.07	.702781	5.23	.297219	14
47	.653808	4.18	.950714	1.07	.703095	5.23	.296905	13
48	.654059	4.17	.950650	1.07	.703409	5.22	.296591	12
49	.654309	4.15	.950586	1.07	.703722	5.23	.296278	11
50	9.654558	4.17	9.950522	1.07	9.704036	5.23	0.295964	10
51	.654808	4.17	.950458	1.07	.704350	5.22	.295650	9
52	.655058	4.15	.950394	1.07	.704663	5.22	.295337	8
53	.655307	4.15	.950330	1.07	.704976	5.23	.295024	7
54	.655556	4.15	.950[illegible]6	1.07	.705290	5.22	.294710	6
55	9.655805	4.15	9.950202	1.07	9.705603	5.22	0.294397	5
56	.656054	4.13	.950138	1.07	.705916	5.20	.294084	4
57	.656302	4.15	.950074	1.07	.706228	5.22	.293772	3
58	.656551	4.13	.950010	1.08	.706541	5.22	.293459	2
59	.656799	4.13	.949945	1.07	.706854	5.20	.293146	1
60	9.657047		9.949881		9.707166		0.292834	0
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M.

M.	Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
0	9.657047	4.13	9.949881	1.08	9.707166	5.20	0.292834	60
1	.657295	4.12	.949816	1.07	.707478	5.20	.292522	59
2	.657542	4.13	.949752	1.07	.707790	5.20	.292210	58
3	.657790	4.12	.949688	1.08	.708102	5.20	.291898	57
4	.658037	4.12	.949623	1.08	.708414	5.20	.291586	56
5	9.658284	4.12	9.949558	1.07	9.708726	5.18	0.291274	55
6	.658531	4.12	.949494	1.08	.709037	5.20	.290963	54
7	.658778	4.12	.949429	1.08	.709349	5.18	.290651	53
8	.659025	4.10	.949364	1.07	.709660	5.18	.290340	52
9	.659271	4.10	.949300	1.08	.709971	5.18	.290029	51
10	9.659517	4.10	9.949235	1.08	9.710282	5.18	0.289718	50
11	.659763	4.10	.949170	1.08	.710593	5.18	.289407	49
12	.660009	4.10	.949105	1.08	.710904	5.18	.289096	48
13	.660255	4.10	.949040	1.08	.711215	5.17	.288785	47
14	.660501	4.08	.948975	1.08	.711525	5.18	.288475	46
15	9.660746	4.08	9.948910	1.08	9.711836	5.17	0.288164	45
16	.660991	4.08	.948845	1.08	.712146	5.17	.287854	44
17	.661236	4.08	.948780	1.08	.712456	5.17	.287544	43
18	.661481	4.08	.948715	1.08	.712766	5.17	.287234	42
19	.661726	4.07	.948650	1.10	.713076	5.17	.286924	41
20	9.661970	4.07	9.948584	1.08	9.713386	5.17	0.286614	40
21	.662214	4.08	.948519	1.08	.713696	5.15	.286304	39
22	.662459	4.07	.948454	1.10	.714005	5.15	.285995	38
23	.662703	4.05	.948388	1.08	.714314	5.17	.285686	37
24	.662946	4.07	.948323	1.10	.714624	5.15	.285376	36
25	9.663190	4.05	9.948257	1.08	9.714933	5.15	0.285067	35
26	.663433	4.07	.948192	1.10	.715242	5.15	.284758	34
27	.663677	4.05	.948126	1.10	.715551	5.15	.284449	33
28	.663920	4.05	.948060	1.08	.715860	5.13	.284140	32
29	.664163	4.05	.947995	1.10	.716168	5.15	.283832	31
30	9.664406	4.03	9.947929	1.10	9.716477	5.13	0.283523	30
31	.664648	4.05	.947863	1.10	.716785	5.13	.283215	29
32	.664891	4.03	.947797	1.10	.717093	5.13	.282907	28
33	.665133	4.03	.947731	1.10	.717401	5.13	.282599	27
34	.665375	4.03	.947665	1.08	.717709	5.13	.282291	26
35	9.665617	4.03	9.947600	1.12	9.718017	5.13	0.281983	25
36	.665859	4.02	.947533	1.10	.718325	5.13	.281675	24
37	.666100	4.03	.947467	1.10	.718633	5.12	.281367	23
38	.666342	4.02	.947401	1.10	.718940	5.13	.281060	22
39	.666583	4.02	.947335	1.10	.719248	5.12	.280752	21
40	9.666824	4.02	9.947269	1.10	9.719555	5.12	0.280445	20
41	.667065	4.00	.947203	1.12	.719862	5.12	.280138	19
42	.667305	4.02	.947136	1.10	.720169	5.12	.279831	18
43	.667546	4.00	.947070	1.10	.720476	5.12	.279524	17
44	.667786	4.02	.947004	1.12	.720783	5.10	.279217	16
45	9.668027	4.00	9.946937	1.10	9.721089	5.12	0.278911	15
46	.668267	3.98	.946871	1.12	.721396	5.10	.278604	14
47	.668506	4.00	.946804	1.10	.721702	5.12	.278298	13
48	.668746	4.00	.946738	1.12	.722009	5.10	.277991	12
49	.668986	3.98	.946671	1.12	.722315	5.10	.277685	11
50	9.669225	3.98	9.946604	1.10	9.722621	5.10	0.277379	10
51	.669464	3.98	.946538	1.12	.722927	5.08	.277073	9
52	.669703	3.98	.946471	1.12	.723232	5.10	.276768	8
53	.669942	3.98	.946404	1.12	.723538	5.10	.276462	7
54	.670181	3.97	.946337	1.12	.723844	5.08	.276156	6
55	9.670419	3.98	9.946270	1.12	9.724149	5.08	0.275851	5
56	.670658	3.97	.946203	1.12	.724454	5.10	.275546	4
57	.670896	3.97	.946136	1.12	.724760	5.08	.275240	3
58	.671134	3.97	.946069	1.13	.725065	5.08	.274935	2
59	.671372	3.95	.946002	1.12	.725370	5.07	.274630	1
60	9.671609		9.945935		9.725674		0.274326	0
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M.

M.	Sin.	D. 1″	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
0	9.671609	3.97	9.945935	1.12	9.725674	5.08	0.274326	60
1	.671847	3.95	.945868	1.13	.725979	5.08	.274021	59
2	.672084	3.95	.945800	1.12	.726284	5.07	.273716	58
3	.672321	3.95	.945733	1.12	.726588	5.07	.273412	57
4	.672558	3.95	.945666	1.13	.726892	5.08	.273108	56
5	9.672795	3.95	9.945598	1.12	9.727197	5.07	0.272803	55
6	.673032	3.93	.945531	1.12	.727501	5.07	.272499	54
7	.673268	3.95	.945464	1.13	.727805	5.07	.272195	53
8	.673505	3.93	.945396	1.13	.728109	5.05	.271891	52
9	.673741	3.93	.945328	1.12	.728412	5.07	.271588	51
10	9.673977	3.93	9.945261	1.13	9.728716	5.07	0.271284	50
11	.674213	3.92	.945193	1.13	.729020	5.05	.270980	49
12	.674448	3.93	.945125	1.12	.729323	5.05	.270677	48
13	.674684	3.92	.945058	1.13	.729626	5.05	.270374	47
14	.674919	3.93	.944990	1.13	.729929	5.07	.270071	46
15	9.675155	3.92	9.944922	1.13	9.730233	5.03	0.269767	45
16	.675390	3.90	.944854	1.13	.730535	5.05	.269465	44
17	.675624	3.92	.944786	1.13	.730838	5.05	.269162	43
18	.675859	3.92	.944718	1.13	.731141	5.05	.268859	42
19	.676094	3.90	.944650	1.13	.731444	5.03	.268556	41
20	9.676328	3.90	9.944582	1.13	9.731746	5.03	0.268254	40
21	.676562	3.90	.944514	1.13	.732048	5.05	.267952	39
22	.676796	3.90	.944446	1.15	.732351	5.03	.267649	38
23	.677030	3.90	.944377	1.13	.732653	5.03	.267347	37
24	.677264	3.90	.944309	1.13	.732955	5.03	.267045	36
25	9.677498	3.88	9.944241	1.15	9.733257	5.02	0.266743	35
26	.677731	3.88	.944172	1.13	.733558	5.03	.266442	34
27	.677964	3.88	.944104	1.13	.733860	5.03	.266140	33
28	.678197	3.88	.944036	1.15	.734162	5.02	.265838	32
29	.678430	3.88	.943967	1.13	.734463	5.02	.265537	31
30	9.678663	3.87	9.943899	1.15	9.734764	5.03	0.265236	30
31	.678895	3.88	.943830	1.15	.735066	5.02	.264934	29
32	.679128	3.87	.943761	1.13	.735367	5.02	.264633	28
33	.679360	3.87	.943693	1.15	.735668	5.02	.264332	27
34	.679592	3.87	.943624	1.15	.735969	5.00	.264031	26
35	9.679824	3.87	9.943555	1.15	9.736269	5.02	0.263731	25
36	.680056	3.87	.943486	1.15	.736570	5.00	.263430	24
37	.680288	3.85	.943417	1.15	.736870	5.02	.263130	23
38	.680519	3.85	.943348	1.15	.737171	5.00	.262829	22
39	.680750	3.87	.943279	1.15	.737471	5.00	.262529	21
40	9.680982	3.85	9.943210	1.15	9.737771	5.00	0.262229	20
41	.681213	3.83	.943141	1.15	.738071	5.00	.261929	19
42	.681443	3.85	.943072	1.15	.738371	5.00	.261629	18
43	.681674	3.85	.943003	1.15	.738671	5.00	.261329	17
44	.681905	3.83	.942934	1.17	.738971	5.00	.261029	16
45	9.682135	3.83	9.942864	1.15	9.739271	4.98	0.260729	15
46	.682365	3.83	.942795	1.15	.739570	5.00	.260430	14
47	.682595	3.83	.942726	1.17	.739870	4.98	.260130	13
48	.682825	3.83	.942656	1.15	.740169	4.98	.259831	12
49	.683055	3.82	.942587	1.17	.740468	4.98	.259532	11
50	9.683284	3.83	9.942517	1.15	9.740767	4.98	0.259233	10
51	.683514	3.82	.942448	1.17	.741066	4.98	.258934	9
52	.683743	3.82	.942378	1.17	.741365	4.98	.258635	8
53	.683972	3.82	.942308	1.15	.741664	4.97	.258336	7
54	.684201	3.82	.942239	1.17	.741962	4.98	.258038	6
55	9.684430	3.80	9.942169	1.17	9.742261	4.97	0.257739	5
56	.684658	3.82	.942099	1.17	.742559	4.98	.257441	4
57	.684887	3.80	.942029	1.17	.742858	4.97	.257142	3
58	.685115	3.80	.941959	1.17	.743156	4.97	.256844	2
59	.685343	3.80	.941889	1.17	.743454	4.97	.256546	1
60	9.685571		9.941819		9.743752		0.256248	0
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M.

M.	Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
0	9.685571	3.80	9.941819	1.17	9.743752	4.97	0.256248	60
1	.685799	3.80	.941749	1.17	.744050	4.97	.255950	59
2	.686027	3.78	.941679	1.17	.744348	4.95	.255652	58
3	.686254	3.80	.941609	1.17	.744645	4.97	.255355	57
4	.686482	3.78	.941539	1.17	.744943	4.95	.255057	56
5	9.686709	3.78	9.941469	1.18	9.745240	4.97	0.254760	55
6	.686936	3.78	.941398	1.17	.745538	4.95	.254462	54
7	.687163	3.77	.941328	1.17	.745835	4.95	.254165	53
8	.687389	3.78	.941258	1.18	.746132	4.95	.253868	52
9	.687616	3.78	.941187	1.17	.746429	4.95	.253571	51
10	9.687843	3.77	9.941117	1.18	9.746726	4.95	0.253274	50
11	.688069	3.77	.941046	1.18	.747023	4.93	.252977	49
12	.688295	3.77	.940975	1.17	.747319	4.95	.252681	48
13	.688521	3.77	.940905	1.18	.747616	4.95	.252384	47
14	.688747	3.75	.940834	1.18	.747913	4.93	.252087	46
15	9.688972	3.77	9.940763	1.17	9.748209	4.93	0.251791	45
16	.689198	3.75	.940693	1.18	.748505	4.93	.251495	44
17	.689423	3.75	.940622	1.18	.748801	4.93	.251199	43
18	.689648	3.75	.940551	1.18	.749097	4.93	.250903	42
19	.689873	3.75	.940480	1.18	.749393	4.93	.250607	41
20	9.690098	3.75	9.940409	1.18	9.749689	4.93	0.250311	40
21	.690323	3.75	.940338	1.18	.749985	4.93	.250015	39
22	.690548	3.73	.940267	1.18	.750281	4.92	.249719	38
23	.690772	3.73	.940196	1.18	.750576	4.93	.249424	37
24	.690996	3.73	.940125	1.18	.750872	4.92	.249128	36
25	9.691220	3.73	9.940054	1.20	9.751167	4.92	0.248833	35
26	.691444	3.73	.939982	1.18	.751462	4.92	.248538	34
27	.691668	3.73	.939911	1.18	.751757	4.92	.248243	33
28	.691892	3.72	.939840	1.20	.752052	4.92	.247948	32
29	.692115	3.73	.939768	1.18	.752347	4.92	.247653	31
30	9.692339	3.72	9.939697	1.20	9.752642	4.92	0.247358	30
31	.692562	3.72	.939625	1.18	.752937	4.90	.247063	29
32	.692785	3.72	.939554	1.20	.753231	4.92	.246769	28
33	.693008	3.72	.939482	1.20	.753526	4.90	.246474	27
34	.693231	3.70	.939410	1.18	.753820	4.92	.246180	26
35	9.693453	3.72	9.939339	1.20	9.754115	4.90	0.245885	25
36	.693676	3.70	.939267	1.20	.754409	4.90	.245591	24
37	.693898	3.70	.939195	1.20	.754703	4.90	.245297	23
38	.694120	3.70	.939123	1.18	.754997	4.90	.245003	22
39	.694342	3.70	.939052	1.20	.755291	4.90	.244709	21
40	9.694564	3.70	9.938980	1.20	9.755585	4.88	0.244415	20
41	.694786	3.68	.938908	1.20	.755878	4.90	.244122	19
42	.695007	3.70	.938836	1.22	.756172	4.88	.243828	18
43	.695229	3.68	.938763	1.20	.756465	4.90	.243535	17
44	.695450	3.68	.938691	1.20	.756759	4.88	.243241	16
45	9.695671	3.68	9.938619	1.20	9.757052	4.88	0.242948	15
46	.695892	3.68	.938547	1.20	.757345	4.88	.242655	14
47	.696113	3.68	.938475	1.22	.757638	4.88	.242362	13
48	.696334	3.67	.938402	1.20	.757931	4.88	.242069	12
49	.696554	3.68	.938330	1.20	.758224	4.88	.241776	11
50	9.696775	3.67	9.938258	1.22	9.758517	4.88	0.241483	10
51	.696995	3.67	.938185	1.20	.758810	4.87	.241190	9
52	.697215	3.67	.938113	1.22	.759102	4.88	.240898	8
53	.697435	3.65	.938040	1.22	.759395	4.87	.240605	7
54	.697654	3.67	.937967	1.20	.759687	4.87	.240313	6
55	9.697874	3.67	9.937895	1.22	9.759979	4.88	0.240021	5
56	.698094	3.65	.937822	1.22	.760272	4.87	.239728	4
57	.698313	3.65	.937749	1.22	.760564	4.87	.239436	3
58	.698532	3.65	.937676	1.20	.760856	4.87	.239144	2
59	.698751	3.65	.937604	1.22	.761148	4.85	.238852	1
60	9.698970		9.937531		9.761439		0.238561	0
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M.

M.	Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
0	9.698970	3.65	9.937531	1.22	9.761439	4.87	0.238561	60
1	.699189	3.63	.937458	1.22	.761731	4.87	.238269	59
2	.699407	3.65	.937385	1.22	.762023	4.85	.237977	58
3	.699626	3.63	.937312	1.23	.762314	4.87	.237686	57
4	.699844	3.63	.937238	1.22	.762606	4.85	.237394	56
5	9.700062	3.63	9.937165	1.22	9.762897	4.85	0.237103	55
6	.700280	3.63	.937092	1.22	.763188	4.85	.236812	54
7	.700498	3.63	.937019	1.22	.763479	4.85	.236521	53
8	.700716	3.62	.936946	1.23	.763770	4.85	.236230	52
9	.700933	3.63	.936872	1.22	.764061	4.85	.235939	51
10	9.701151	3.62	9.936799	1.23	9.764352	4.85	0.235648	50
11	.701368	3.62	.936725	1.22	.764643	4.83	.235357	49
12	.701585	3.62	.936652	1.23	.764933	4.85	.235067	48
13	.701802	3.62	.936578	1.22	.765224	4.83	.234776	47
14	.702019	3.62	.936505	1.23	.765514	4.85	.234486	46
15	9.702236	3.60	9.936431	1.23	9.765805	4.83	0.234195	45
16	.702452	3.62	.936357	1.22	.766095	4.83	.233905	44
17	.702669	3.60	.936284	1.23	.766385	4.83	.233615	43
18	.702885	3.60	.936210	1.23	.766675	4.83	.233325	42
19	.703101	3.60	.936136	1.23	.766965	4.83	.233035	41
20	9.703317	3.60	9.936062	1.23	9.767255	4.83	0.232745	40
21	.703533	3.60	.935988	1.23	.767545	4.82	.232455	39
22	.703749	3.58	.935914	1.23	.767834	4.83	.232166	38
23	.703964	3.58	.935840	1.23	.768124	4.83	.231876	37
24	.704179	3.60	.935766	1.23	.768414	4.82	.231586	36
25	9.704395	3.58	9.935692	1.23	9.768703	4.82	0.231297	35
26	.704610	3.58	.935618	1.25	.768992	4.82	.231008	34
27	.704825	3.58	.935543	1.23	.769281	4.83	.230719	33
28	.705040	3.57	.935469	1.23	.769571	4.82	.230429	32
29	.705254	3.58	.935395	1.25	.769860	4.80	.230140	31
30	9.705469	3.57	9.935320	1.23	9.770148	4.82	0.229852	30
31	.705683	3.58	.935246	1.25	.770437	4.82	.229563	29
32	.705898	3.57	.935171	1.23	.770726	4.82	.229274	28
33	.706112	3.57	.935097	1.25	.771015	4.80	.228985	27
34	.706326	3.55	.935022	1.23	.771303	4.82	.228697	26
35	9.706539	3.57	9.934948	1.25	9.771592	4.80	0.228408	25
36	.706753	3.57	.934873	1.25	.771880	4.80	.228120	24
37	.706967	3.55	.934798	1.25	.772168	4.82	.227832	23
38	.707180	3.55	.934723	1.23	.772457	4.80	.227543	22
39	.707393	3.55	.934649	1.25	.772745	4.80	.227255	21
40	9.707606	3.55	9.934574	1.25	9.773033	4.80	0.226967	20
41	.707819	3.55	.934499	1.25	.773321	4.78	.226679	19
42	.708032	3.55	.934424	1.25	.773608	4.80	.226392	18
43	.708245	3.55	.934349	1.25	.773896	4.80	.226104	17
44	.708458	3.53	.934274	1.25	.774184	4.78	.225816	16
45	9.708670	3.53	9.934199	1.27	9.774471	4.80	0.225529	15
46	.708882	3.53	.934123	1.25	.774759	4.78	.225241	14
47	.709094	3.53	.934048	1.25	.775046	4.78	.224954	13
48	.709306	3.53	.933973	1.25	.775333	4.80	.224667	12
49	.709518	3.53	.933898	1.27	.775621	4.78	.224379	11
50	9.709730	3.52	9.933822	1.25	9.775908	4.78	0.224092	10
51	.709941	3.53	.933747	1.27	.776195	4.78	.223805	9
52	.710153	3.52	.933671	1.25	.776482	4.77	.223518	8
53	.710364	3.52	.933596	1.27	.776768	4.78	.223232	7
54	.710575	3.52	.933520	1.25	.777055	4.78	.222945	6
55	9.710786	3.52	9.933445	1.27	9.777342	4.77	0.222658	5
56	.710997	3.52	.933369	1.27	.777628	4.78	.222372	4
57	.711208	3.52	.933293	1.27	.777915	4.77	.222085	3
58	.711419	3.50	.933217	1.27	.778201	4.78	.221799	2
59	.711629	3.50	.933141	1.25	.778488	4.77	.221512	1
60	9.711839		9.933066		9.778774		0.221226	0
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M

M.	Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
0	9.711839	3.52	9.933066	1.27	9.778774	4.77	0.221226	60
1	.712050	3.50	.932990	1.27	.779060	4.77	.220940	59
2	.712260	3.48	.932914	1.27	.779346	4.77	.220654	58
3	.712469	3.50	.932838	1.27	.779632	4.77	.220368	57
4	.712679	3.50	.932762	1.28	.779918	4.75	.220082	56
5	9.712889	3.48	9.932685	1.27	9.780203	4.77	0.219797	55
6	.713098	3.50	.932609	1.27	.780489	4.77	.219511	54
7	.713308	3.48	.932533	1.27	.780775	4.75	.219225	53
8	.713517	3.48	.932457	1.28	.781060	4.77	.218940	52
9	.713726	3.48	.932380	1.27	.781346	4.75	.218654	51
10	9.713935	3.48	9.932304	1.27	9.781631	4.75	0.218369	50
11	.714144	3.47	.932228	1.28	.781916	4.75	.218084	49
12	.714352	3.48	.932151	1.27	.782201	4.75	.217799	48
13	.714561	3.47	.932075	1.28	.782486	4.75	.217514	47
14	.714769	3.48	.931998	1.28	.782771	4.75	.217229	46
15	9.714978	3.47	9.931921	1.27	9.783056	4.75	0.216944	45
16	.715186	3.47	.931845	1.28	.783341	4.75	.216659	44
17	.715394	3.47	.931768	1.28	.783626	4.73	.216374	43
18	.715602	3.45	.931691	1.28	.783910	4.75	.216090	42
19	.715809	3.47	.931614	1.28	.784195	4.73	.215805	41
20	9.716017	3.45	9.931537	1.28	9.784479	4.75	0.215521	40
21	.716224	3.47	.931460	1.28	.784764	4.73	.215236	39
22	.716432	3.45	.931383	1.28	.785048	4.73	.214952	38
23	.716639	3.45	.931306	1.28	.785332	4.73	.214668	37
24	.716846	3.45	.931229	1.28	.785616	4.73	.214384	36
25	9.717053	3.43	9.931152	1.28	9.785900	4.73	0.214100	35
26	.717259	3.45	.931075	1.28	.786184	4.73	.213816	34
27	.717466	3.45	.930998	1.28	.786468	4.73	.213532	33
28	.717673	3.43	.930921	1.30	.786752	4.73	.213248	32
29	.717879	3.43	.930843	1.28	.787036	4.72	.212964	31
30	9.718085	3.43	9.930766	1.30	9.787319	4.73	0.212681	30
31	.718291	3.43	.930688	1.28	.787603	4.72	.212397	29
32	.718497	3.43	.930611	1.30	.787886	4.73	.212114	28
33	.718703	3.43	.930533	1.28	.788170	4.72	.211830	27
34	.718909	3.42	.930456	1.30	.788453	4.72	.211547	26
35	9.719114	3.43	9.930378	1.30	9.788736	4.72	0.211264	25
36	.719320	3.42	.930300	1.28	.789019	4.72	.210981	24
37	.719525	3.42	.930223	1.30	.789302	4.72	.210698	23
38	.719730	3.42	.930145	1.30	.789585	4.72	.210415	22
39	.719935	3.42	.930067	1.30	.789868	4.72	.210132	21
40	9.720140	3.42	9.929989	1.30	9.790151	4.72	0.209849	20
41	.720345	3.40	.929911	1.30	.790434	4.70	.209566	19
42	.720549	3.42	.929833	1.30	.790716	4.72	.209284	18
43	.720754	3.40	.929755	1.30	.790999	4.70	.209001	17
44	.720958	3.40	.929677	1.30	.791281	4.70	.208719	16
45	9.721162	3.40	9.929599	1.30	9.791563	4.72	0.208437	15
46	.721366	3.40	.929521	1.32	.791846	4.70	.208154	14
47	.721570	3.40	.929442	1.30	.792128	4.70	.207872	13
48	.721774	3.40	.929364	1.30	.792410	4.70	.207590	12
49	.721978	3.38	.929286	1.32	.792692	4.70	.207308	11
50	9.722181	3.40	9.929207	1.30	9.792974	4.70	0.207026	10
51	.722385	3.38	.929129	1.32	.793256	4.70	.206744	9
52	.722588	3.38	.929050	1.30	.793538	4.68	.206462	8
53	.722791	3.38	.928972	1.32	.793819	4.70	.206181	7
54	.722994	3.38	.928893	1.30	.794101	4.70	.205899	6
55	9.723197	3.38	9.928815	1.32	9.794383	4.68	0.205617	5
56	.723400	3.38	.928736	1.32	.794664	4.70	.205336	4
57	.723603	3.37	.928657	1.32	.794946	4.68	.205054	3
58	.723805	3.37	.928578	1.32	.795227	4.68	.204773	2
59	.724007	3.38	.928499	1.32	.795508	4.68	.204492	1
60	9.724210		9.928420		9.795789		0.204211	0
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M.

M.	Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
0	9.724210	3.37	9.928420	1.30	9.795789	4.68	0.204211	60
1	.724412	3.37	.928342	1.32	.796070	4.68	.203930	59
2	.724614	3.37	.928263	1.33	.796351	4.68	.203649	58
3	.724816	3.35	.928183	1.32	.796632	4.68	.203368	57
4	.725017	3.37	.928104	1.32	.796913	4.68	.203087	56
5	9.725219	3.33	9.928025	1.32	9.797194	4.67	0.202806	55
6	.725420	3.37	.927946	1.32	.797474	4.68	.202526	54
[illegible]	.725622	3.35	.927867	1.33	.797755	4.68	.202245	53
[illegible]	.725823	3.35	.927787	1.32	.798036	4.67	.201964	52
9	.726024	3.35	.927708	1.32	.798316	4.67	.201684	51
10	9.726225	3.35	9.927629	1.33	9.798596	4.68	0.201404	50
11	.726426	3.33	.927549	1.32	.798877	4.67	.201123	49
12	.726626	3.35	.927470	1.33	.799157	4.67	.200843	48
13	.726827	3.33	.927390	1.33	.799437	4.67	.200563	47
14	.727027	3.35	.927310	1.32	.799717	4.67	.200283	46
15	9.727228	3.33	9.927231	1.33	9.799997	4.67	0.200003	45
16	.727428	3.33	.927151	1.33	.800277	4.67	.199723	[illegible]
17	.727628	3.33	.927071	1.33	.800557	4.65	.199443	43
18	.727828	3.32	.926991	1.33	.800836	4.67	.199164	42
19	.728027	3.33	.926911	1.33	.801116	4.67	.198884	41
20	9.728227	3.33	9.926831	1.33	9.801396	4.65	0.198604	40
21	.728427	3.32	.926751	1.33	.801675	4.67	.198325	39
22	.728626	3.32	.926671	1.33	.801955	4.65	.198045	38
23	.728825	3.32	.926591	1.33	.802234	4.65	.197766	37
24	.729024	3.32	.926511	1.33	.802513	4.65	.197487	36
25	9.729223	3.32	9.926431	1.33	9.802792	4.67	0.197208	35
26	.729422	3.32	.926351	1.35	.803072	4.65	.196928	34
27	.729621	3.32	.926270	1.33	.803351	4.65	.196649	33
28	.729820	3.30	.926190	1.33	.803630	4.65	.196370	32
29	.730018	3.32	.926110	1.35	.803909	4.63	.196091	31
30	9.730217	3.30	9.926029	1.33	9.804187	4.65	0.195813	30
31	.730415	3.30	.925949	1.35	.804466	4.65	.195534	29
32	.730613	3.30	.925868	1.33	.804745	4.63	.195255	28
33	.730811	3.30	.925788	1.35	.805023	4.65	.194977	27
34	.731009	3.28	.925707	1.35	.805302	4.63	.194698	26
35	9.731206	3.30	9.925626	1.35	9.805580	4.65	0.194420	25
36	.731404	3.30	.925545	1.33	.805859	4.63	.194141	24
37	.731602	3.28	.925465	1.[illegible]	.806137	4.63	.193863	23
38	.731799	3.28	.925384	1.35	.806415	4.63	.193585	22
39	.731996	3.28	.925303	1.35	.806693	4.63	.193307	21
40	9.732193	3.28	9.925222	1.35	9.806971	4.63	0.193029	20
41	.732390	3.28	.925141	1.35	.807249	4.63	.192751	19
42	.732587	3.28	.925060	1.35	.807527	4.63	.192473	18
43	.732784	3.27	.924979	1.37	.807805	4.63	.192195	17
[illegible]	.732980	3.28	.924897	1.35	.808083	4.63	.191917	16
45	9.733177	3.27	9.924816	1.35	9.808361	4.62	0.191639	15
46	.733373	3.27	.924735	1.35	.808638	4.63	.191362	14
47	.733569	3.27	.924654	1.37	.808916	4.62	.191084	13
48	.733765	3.27	.924572	1.35	.809193	4.63	.190807	12
49	.733961	3.27	.924491	1.37	.809471	4.62	.190529	11
50	9.734157	3.27	9.924409	1.35	9.809748	4.62	0.190252	10
51	.734353	3.27	.924328	1.37	.810025	4.62	.189975	9
52	.734549	3.25	.924246	1.37	.810302	4.63	.189698	8
53	.734744	3.25	.924164	1.35	.810580	4.62	.189420	7
54	.734939	3.27	.924083	1.37	.810857	4.62	.189143	6
55	9.735135	3.25	9.924001	1.37	9.811134	4.60	0.188866	5
56	.735330	3.25	.923919	1.37	.811410	4.62	.188590	4
57	.735525	3.23	.923837	1.37	.811687	4.62	.188313	3
58	.735719	3.25	.923755	1.37	.811964	4.62	.188036	2
59	.735914	3.25	.923673	1.37	.812241	4.60	.187759	1
60	9.736109		9.923591		9.812517		0.187483	0
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M.

M.	Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
0	9.736109	3.23	9.923591	1.37	9.812517	4.62	0.187483	60
1	.736303	3.25	.923509	1.37	.812794	4.60	.187206	59
2	.736498	3.23	.923427	1.37	.813070	4.62	.186930	58
3	.736692	3.23	.923345	1.37	.813347	4.60	.186653	57
4	.736886	3.23	.923263	1.37	.813623	4.60	.186377	56
5	9.737080	3.23	9.923181	1.38	9.813899	4.62	0.186101	55
6	.737274	3.22	.923098	1.37	.814176	4.60	.185824	54
7	.737467	3.23	.923016	1.38	.814452	4.60	.185548	53
8	.737661	3.23	.922933	1.37	.814728	4.60	.185272	52
9	.737855	3.22	.922851	1.38	.815004	4.60	.184996	51
10	9.738048	3.22	9.922768	1.37	9.815280	4.58	0.184720	50
11	.738241	3.22	.922686	1.38	.815555	4.60	.184445	49
12	.738434	3.22	.922603	1.38	.815831	4.60	.184169	48
13	.738627	3.22	.922520	1.37	.816107	4.58	.183893	47
14	.738820	3.22	.922438	1.38	.816382	4.60	.183618	46
15	9.739013	3.22	9.922355	1.38	9.816658	4.58	0.183342	45
16	.739206	3.20	.922272	1.38	.816933	4.60	.183067	44
17	.739398	3.20	.922189	1.38	.817209	4.58	.182791	43
18	.739590	3.22	.922106	1.38	.817484	4.58	.182516	42
19	.739783	3.20	.922023	1.38	.817759	4.60	.182241	41
20	9.739975	3.20	9.921940	1.38	9.818035	4.58	0.181965	40
21	.740167	3.20	.921857	1.38	.818310	4.58	.181690	39
22	.740359	3.18	.921774	1.38	.818585	4.58	.181415	38
23	.740550	3.20	.921691	1.40	.818860	4.58	.181140	37
24	.740742	3.20	.921607	1.38	.819135	4.58	.180865	36
25	9.740934	3.18	9.921524	1.38	9.819410	4.57	0.180590	35
26	.741125	3.18	.921441	1.40	.819684	4.58	.180316	34
27	.741316	3.20	.921357	1.38	.819959	4.58	.180041	33
28	.741508	3.18	.921274	1.40	.820234	4.57	.179766	32
29	.741699	3.17	.921190	1.38	.820508	4.58	.179492	31
30	9.741889	3.18	9.921107	1.40	9.820783	4.57	0.179217	30
31	.742080	3.18	.921023	1.40	.821057	4.58	.178943	29
32	.742271	3.18	.920939	1.38	.821332	4.57	.178668	28
33	.742462	3.17	.920856	1.40	.821606	4.57	.178394	27
34	.742652	3.17	.920772	1.40	.821880	4.57	.178120	26
35	9.742842	3.18	9.920688	1.40	9.822154	4.58	0.177846	25
36	.743033	3.17	.920604	1.40	.822429	4.57	.177571	24
37	.743223	3.17	.920520	1.40	.822703	4.57	.177297	23
38	.743413	3.15	.920436	1.40	.822977	4.57	.177023	22
39	.743602	3.17	.920352	1.40	.823251	4.55	.176749	21
40	9.743792	3.17	9.920268	1.40	9.823524	4.57	0.176476	20
41	.743982	3.15	.920184	1.42	.823798	4.57	.176202	19
42	.744171	3.17	.920099	1.40	.824072	4.55	.175928	18
43	.744361	3.15	.920015	1.40	.824345	4.57	.175655	17
44	.744550	3.15	.919931	1.42	.824619	4.57	.175381	16
45	9.744739	3.15	9.919846	1.40	9.824893	4.55	0.175107	15
46	.744928	3.15	.919762	1.42	.825166	4.55	.174834	14
47	.745117	3.15	.919677	1.40	.825439	4.57	.174561	13
48	.745306	3.13	.919593	1.42	.825713	4.55	.174287	12
49	.745494	3.15	.919508	1.40	.825986	4.55	.174014	11
50	9.745683	3.13	9.919424	1.42	9.826259	4.55	0.173741	10
51	.745871	3.15	.919339	1.42	.826532	4.55	.173468	9
52	.746060	3.13	.919254	1.42	.826805	4.55	.173195	8
53	.746248	3.13	.919169	1.40	.827078	4.55	.172922	7
54	.746436	3.13	.919085	1.42	.827351	4.55	.172649	6
55	9.746624	3.13	9.919000	1.42	9.827624	4.55	0.172376	5
56	.746812	3.12	.918915	1.42	.827897	4.55	.172103	4
57	.746999	3.13	.918830	1.42	.828170	4.53	.171830	3
58	.747187	3.12	.918745	1.43	.828442	4.55	.171558	2
59	.747374	3.13	.918659	1.42	.828715	4.53	.171285	1
60	9.747562		9.918574		9.828987		0.171013	0
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M.

M	Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
0	9.747562	3.12	9.918574	1.42	9.828987	4.55	0.171013	60
1	.747749	3.12	.918489	1.42	.829260	4.53	.170740	59
2	.747936	3.12	.918404	1.43	.829532	4.55	.170468	58
3	.748123	3.12	.918318	1.42	.829805	4.53	.170195	57
4	.748310	3.12	.918233	1.43	.830077	4.53	.169923	56
5	9.748497	3.10	9.918147	1.42	9.830349	4.53	0.169651	55
6	.748683	3.12	.918062	1.43	.830621	4.53	.169379	54
7	.748870	3.10	.917976	1.42	.830893	4.53	.169107	53
8	.749056	3.12	.917891	1.43	.831165	4.53	.168835	52
9	.749243	3.10	.917805	1.43	.831437	4.53	.168563	51
10	9.749429	3.10	9.917719	1.42	9.831709	4.53	0.168291	50
11	.749615	3.10	.917634	1.43	.831981	4.53	.168019	49
12	.749801	3.10	.917548	1.43	.832253	4.53	.167747	48
13	.749987	3.08	.917462	1.43	.832525	4.52	.167475	47
14	.750172	3.10	.917376	1.43	.832796	4.53	.167204	46
15	9.750358	3.08	9.917290	1.43	9.833068	4.52	0.166932	45
16	.750543	3.10	.917204	1.43	.833339	4.53	.166661	44
17	.750729	3.08	.917118	1.43	.833611	4.52	.166389	43
18	.750914	3.08	.917032	1.43	.833882	4.53	.166118	42
19	.751099	3.08	.916946	1.45	.834154	4.52	.165846	41
20	9.751284	3.08	9.916859	1.43	9.834425	4.52	0.165575	40
21	.751469	3.08	.916773	1.43	.834696	4.52	.165304	39
22	.751654	3.08	.916687	1.45	.834967	4.52	.165033	38
23	.751839	3.07	.916600	1.43	.835238	4.52	.164762	37
24	.752023	3.08	.916514	1.45	.835509	4.52	.164491	36
25	9.752208	3.07	9.916427	1.43	9.835780	4.52	0.164220	35
26	.752392	3.07	.916341	1.45	.836051	4.52	.163949	34
27	.752576	3.07	.916254	1.45	.836322	4.52	.163678	33
28	.752760	3.07	.916167	1.43	.836593	4.52	.163407	32
29	.752944	3.07	.916081	1.45	.836864	4.50	.163136	31
30	9.753128	3.07	9.915994	1.45	9.837134	4.52	0.162866	30
31	.753312	3.05	.915907	1.45	.837405	4.50	.162595	29
32	.753495	3.07	.915820	1.45	.837675	4.52	.162325	28
33	.753679	3.05	.915733	1.45	.837946	4.50	.162054	27
34	.753862	3.07	.915646	1.45	.838216	4.52	.161784	26
35	9.754046	3.05	9.915559	1.45	9.838487	4.50	0.161513	25
36	.754229	3.05	.915472	1.45	.838757	4.50	.161243	24
37	.754412	3.05	.915385	1.47	.839027	4.50	.160973	23
38	.754595	3.05	.915297	1.45	.839297	4.52	.160703	22
39	.754778	3.03	.915210	1.45	.839568	4.50	.160432	21
40	9.754960	3.05	9.915123	1.47	9.839838	4.50	0.160162	20
41	.755143	3.05	.915035	1.45	.840108	4.50	.159892	19
42	.755326	3.03	.914948	1.47	.840378	4.50	.159622	18
43	.755508	3.03	.914860	1.45	.840648	4.48	.159352	17
44	.755690	3.03	.914773	1.47	.840917	4.50	.159083	16
45	9.755872	3.03	9.914685	1.45	9.841187	4.50	0.158813	15
46	.756054	3.03	.914598	1.47	.841457	4.50	.158543	14
47	.756236	3.03	.914510	1.47	.841727	4.48	.158273	13
48	.756418	3.03	.914422	1.47	.841996	4.50	.158004	12
49	.756600	3.03	.914334	1.47	.842266	4.48	.157734	11
50	9.756782	3.02	9.914246	1.47	9.842535	4.50	0.157465	10
51	.756963	3.02	.914158	1.47	.842805	4.48	.157195	9
52	.757144	3.03	.914070	1.47	.843074	4.48	.156926	8
53	.757326	3.02	.913982	1.47	.843343	4.48	.156657	7
54	.757507	3.02	.913894	1.47	.843612	4.50	.156388	6
55	9.757688	3.02	9.913806	1.47	9.843882	4.48	0.156118	5
56	.757869	3.02	.913718	1.47	.844151	4.48	.155849	4
57	.758050	3.00	.913630	1.48	.844420	4.48	.155580	3
58	.758230	3.02	.913541	1.47	.844689	4.48	.155311	2
59	.758411	3.00	.913453	1.47	.844958	4.48	.155042	1
60	9.758591		9.913365		9.845227		0.154773	0
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M.

M.	Sine.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
0	9.758591	3.02	9.913365	1.48	9.845227	4.48	0.154773	60
1	.758772	3.00	.913276	1.48	.845496	4.47	.154504	59
2	.758952	3.00	.913187	1.47	.845764	4.48	.154236	58
3	.759132	3.00	.913099	1.48	.846033	4.48	.153967	57
4	.759312	3.00	.913010	1.47	.846302	4.47	.153698	56
5	9.759492	3.00	9.912922	1.48	9.846570	4.48	0.153430	55
6	.759672	3.00	.912833	1.48	.846839	4.48	.153161	54
7	.759852	2.98	.912744	1.48	.847108	4.47	.152892	53
8	.760031	3.00	.912655	1.48	.847376	4.47	.152624	52
9	.760211	2.98	.912566	1.48	.847644	4.48	.152356	51
10	9.760390	2.98	9.912477	1.48	9.847913	4.47	0.152087	50
11	.760569	2.98	.912388	1.48	.848181	4.47	.151819	49
12	.760748	2.98	.912299	1.48	.848449	4.47	.151551	48
13	.760927	2.98	.912210	1.48	.848717	4.48	.151283	47
14	.761106	2.98	.912121	1.50	.848986	4.47	.151014	46
15	9.761285	2.98	9.912031	1.48	9.849254	4.47	0.150746	45
16	.761464	2.97	.911942	1.48	.849522	4.47	.150478	44
17	.761642	2.98	.911853	1.50	.849790	4.45	.150210	43
18	.761821	2.97	.911763	1.48	.850057	4.47	.149943	42
19	.761999	2.97	.911674	1.50	.850325	4.47	.149675	41
20	9.762177	2.98	9.911584	1.48	9.850593	4.47	0.149407	40
21	.762356	2.97	.911495	1.50	.850861	4.47	.149139	39
22	.762534	2.97	.911405	1.50	.851129	4.45	.148871	38
23	.762712	2.95	.911315	1.48	.851396	4.47	.148604	37
24	.762889	2.97	.911226	1.50	.851664	4.45	.148336	36
25	9.763067	2.97	9.911136	1.50	9.851931	4.47	0.148069	35
26	.763245	2.95	.911046	1.50	.852199	4.45	.147801	34
27	.763422	2.97	.910956	1.50	.852466	4.45	.147534	33
28	.763600	2.95	.910866	1.50	.852733	4.47	.147267	32
29	.763777	2.95	.910776	1.50	.853001	4.45	.146999	31
30	9.763954	2.95	9.910686	1.50	9.853268	4.45	0.146732	30
31	.764131	2.95	.910596	1.50	.853535	4.45	.146465	29
32	.764308	2.95	.910506	1.52	.853802	4.45	.146198	28
33	.764485	2.95	.910415	1.50	.854069	4.45	.145931	27
34	.764662	2.93	.910325	1.50	.854336	4.45	.145664	26
35	9.764838	2.95	9.910235	1.52	9.854603	4.45	0.145397	25
36	.765015	2.93	.910144	1.50	.854870	4.45	.145130	24
37	.765191	2.93	.910054	1.52	.855137	4.45	.144863	23
38	.765367	2.95	.909963	1.50	.855404	4.45	.144596	22
39	.765544	2.93	.909873	1.52	.855671	4.45	.144329	21
40	9.765720	2.93	9.909782	1.52	9.855938	4.43	0.144062	20
41	.765896	2.93	.909691	1.50	.856204	4.45	.143796	19
42	.766072	2.92	.909601	1.52	.856471	4.43	.143529	18
43	.766247	2.93	.909510	1.52	.856737	4.45	.143263	17
44	.766423	2.92	.909419	1.52	.857004	4.43	.142996	16
45	9.766598	2.93	9.909328	1.52	9.857270	4.45	0.142730	15
46	.766774	2.92	.909237	1.52	.857537	4.43	.142463	14
47	.766949	2.92	.909146	1.52	.857803	4.43	.142197	13
48	.767124	2.93	.909055	1.52	.858069	4.45	.141931	12
49	.767300	2.92	.908964	1.52	.858336	4.43	.141664	11
50	9.767475	2.90	9.908873	1.53	9.858602	4.43	0.141398	10
51	.767649	2.92	.908781	1.52	.858868	4.43	.141132	9
52	.767824	2.92	.908690	1.52	.859134	4.43	.140866	8
53	.767999	2.90	.908599	1.53	.859400	4.43	.140600	7
54	.768173	2.92	.908507	1.52	.859666	4.43	.140334	6
55	9.768348	2.90	9.908416	1.53	9.859932	4.43	0.140068	5
56	.768522	2.92	.908324	1.52	.860198	4.43	.139802	4
57	.768697	2.90	.908233	1.53	.860464	4.43	.139536	3
58	.768871	2.90	.908141	1.53	.860730	4.42	.139270	2
59	.769045	2.90	.908049	1.52	.860995	4.43	.139005	1
60	9.769219		9.907958		9.861261		0.138739	0
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M.

M	Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
0	9.769219	2.90	9.907958	1.53	9.861261	4.43	0.138739	60
1	.769393	2.88	.907866	1.53	.861527	4.42	.138473	59
2	.769566	2.90	.907774	1.53	.861792	4.43	.138208	58
3	.769740	2.88	.907682	1.53	.862058	4.42	.137942	57
4	.769913	2.90	.907590	1.53	.862323	4.43	.137677	56
5	9.770087	2.88	9.907498	1.53	9.862589	4.42	0.137411	55
6	.770260	2.88	.907406	1.53	.862854	4.42	.137146	54
7	.770433	2.88	.907314	1.53	.863119	4.43	.136881	53
8	.770606	2.88	.907222	1.55	.863385	4.42	.136615	52
9	.770779	2.88	.907129	1.53	.863650	4.42	.136350	51
10	9.770952	2.88	9.907037	1.53	9.863915	4.42	0.136085	50
11	.771125	2.88	.906945	1.55	.864180	4.42	.135820	49
12	.771298	2.87	.906852	1.53	.864445	4.42	.135555	48
13	.771470	2.88	.906760	1.55	.864710	4.42	.135290	47
14	.771643	2.87	.906667	1.53	.864975	4.42	.135025	46
15	9.771815	2.87	9.906575	1.55	9.865240	4.42	0.134760	45
16	.771987	2.87	.906482	1.55	.865505	4.42	.134495	44
17	.772159	2.87	.906389	1.55	.865770	4.42	.134230	43
18	.772331	2.87	.906296	1.53	.866035	4.42	.133965	42
19	.772503	2.87	.906204	1.55	.866300	4.40	.133700	41
20	9.772675	2.87	9.906111	1.55	9.866564	4.42	0.133436	40
21	.772847	2.85	.906018	1.55	.866829	4.42	.133171	39
22	.773018	2.87	.905925	1.55	.867094	4.40	.132906	38
23	.773190	2.85	.905832	1.55	.867358	4.42	.132642	37
24	.773361	2.87	.905739	1.57	.867623	4.40	.132377	36
25	9.773533	2.85	9.905645	1.55	9.867887	4.42	0.132113	35
26	.773704	2.85	.905552	1.55	.868152	4.40	.131848	34
27	.773875	2.85	.905459	1.55	.868416	4.40	.131584	33
28	.774046	2.85	.905366	1.57	.868680	4.42	.131320	32
29	.774217	2.85	.905272	1.55	.868945	4.40	.131055	31
30	9.774388	2.83	9.905179	1.57	9.869209	4.40	0.130791	30
31	.774558	2.85	.905085	1.55	.869473	4.40	.130527	29
32	.774729	2.83	.904992	1.57	.869737	4.40	.130263	28
33	.774899	2.85	.904898	1.57	.870001	4.40	.129999	27
34	.775070	2.83	.904804	1.55	.870265	4.40	.129735	26
35	9.775240	2.83	9.904711	1.57	9.870529	4.40	0.129471	25
36	.775410	2.83	.904617	1.57	.870793	4.40	.129207	24
37	.775580	2.83	.904523	1.57	.871057	4.40	.128943	23
38	.775750	2.83	.904429	1.57	.871321	4.40	.128679	22
39	.775920	2.83	.904335	1.57	.871585	4.40	.128415	21
40	9.776090	2.82	9.904241	1.57	9.871849	4.38	0.128151	20
41	.776259	2.83	.904147	1.57	.872112	4.40	.127888	19
42	.776429	2.82	.904053	1.57	.872376	4.40	.127624	18
43	.776598	2.83	.903959	1.58	.872640	4.38	.127360	17
44	.776768	2.82	.903864	1.57	.872903	4.40	.127097	16
45	9.776937	2.82	9.903770	1.57	9.873167	4.38	0.126833	15
46	.777106	2.82	.903676	1.58	.873430	4.40	.126570	14
47	.777275	2.82	.903581	1.57	.873694	4.38	.126306	13
48	.777444	2.82	.903487	1.58	.873957	4.38	.126043	12
49	.777613	2.80	.903392	1.57	.874220	4.40	.125780	11
50	9.777781	2.82	9.903298	1.58	9.874484	4.38	0.125516	10
51	.777950	2.82	.903203	1.58	.874747	4.38	.125253	9
52	.778119	2.80	.903108	1.57	.875010	4.38	.124990	8
53	.778287	2.80	.903014	1.58	.875273	4.40	.124727	7
54	.778455	2.82	.902919	1.58	.875537	4.38	.124463	6
55	9.778624	2.80	9.902824	1.58	9.875800	4.38	0.124200	5
56	.778792	2.80	.902729	1.58	.876063	4.38	.123937	4
57	.778960	2.80	.902634	1.58	.876326	4.38	.123674	3
58	.779128	2.78	.902539	1.58	.876589	4.38	.123411	2
59	.779295	2.80	.902444	1.58	.876852	4.37	.123148	1
60	9.779463		9.902349		9.877114		0.122886	0
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M

Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
9.779463	2.80	9.902349	1.60	9.877114	4.38	0.122886	60
.779631	2.78	.902253	1.58	.877377	4.38	.122623	59
.779798	2.80	.902158	1.58	.877640	4.38	.122360	58
.779966	2.78	.902063	1.60	.877903	4.37	.122097	57
.780133	2.78	.901967	1.58	.878165	4.38	.121835	56
9.780300	2.78	9.901872	1.60	9.878428	4.38	0.121572	55
.780467	2.78	.901776	1.58	.878691	4.37	.121309	54
.780634	2.78	.901681	1.60	.878953	4.38	.121047	53
.780801	2.78	.901585	1.58	.879216	4.37	.120784	52
.780968	2.77	.901490	1.60	.879478	4.38	.120522	51
9.781134	2.78	9.901394	1.60	9.879741	4.37	0.120259	50
.781301	2.78	.901298	1.60	.880003	4.37	.119997	49
.781468	2.77	.901202	1.60	.880265	4.38	.119735	48
.781634	2.77	.901106	1.60	.880528	4.37	.119472	47
.781800	2.77	.901010	1.60	.880790	4.37	.119210	46
9.781966	2.77	9.900914	1.60	9.881052	4.37	0.118948	45
.782132	2.77	.900818	1.60	.881314	4.38	.118686	44
.782298	2.77	.900722	1.60	.881577	4.37	.118423	43
.782464	2.77	.900626	1.62	.881839	4.37	.118161	42
.782630	2.77	.900529	1.60	.882101	4.37	.117899	41
9.782796	2.75	9.900433	1.60	9.882363	4.37	0.117637	40
.782961	2.77	.900337	1.62	.882625	4.37	.117375	39
.783127	2.75	.900240	1.60	.882887	4.35	.117113	38
.783292	2.77	.900144	1.62	.883148	4.37	.116852	37
.783458	2.75	.900047	1.60	.883410	4.37	.116590	36
9.783623	2.75	9.899951	1.62	9.883672	4.37	0.116328	35
.783788	2.75	.899854	1.62	.883934	4.37	.116066	34
.783953	2.75	.899757	1.62	.884196	4.35	.115804	33
.784118	2.73	.899660	1.60	.884457	4.37	.115543	32
.784282	2.75	.899564	1.62	.884719	4.35	.115281	31
9.784447	2.75	9.899467	1.62	9.884980	4.37	0.115020	30
.784612	2.73	.899370	1.62	.885242	4.37	.114758	29
.784776	2.75	.899273	1.62	.885504	4.35	.114496	28
.784941	2.73	.899176	1.63	.885765	4.35	.114235	27
.785105	2.73	.899078	1.62	.886026	4.37	.113974	26
9.785269	2.73	9.898981	1.62	9.886288	4.35	0.113712	25
.785433	2.73	.898884	1.62	.886549	4.37	.113451	24
.785597	2.73	.898787	1.63	.886811	4.35	.113189	23
.785761	2.73	.898689	1.62	.887072	4.35	.112928	22
.785925	2.73	.898592	1.63	.887333	4.35	.112667	21
9.786089	2.72	9.898494	1.62	9.887594	4.35	0.112406	20
.786252	2.73	.898397	1.63	.887855	4.35	.112145	19
.786416	2.72	.898299	1.62	.888116	4.37	.111884	18
.786579	2.72	.898202	1.63	.888378	4.35	.111622	17
.786742	2.73	.898104	1.63	.888639	4.35	.111361	16
9.786906	2.72	9.898006	1.63	9.888900	4.35	0.111100	15
.787069	2.72	.897908	1.63	.889161	4.33	.110839	14
.787232	2.72	.897810	1.63	.889421	4.35	.110579	13
.787395	2.70	.897712	1.63	.889682	4.35	.110318	12
.787557	2.72	.897614	1.63	.889943	4.35	.110057	11
9.787720	2.72	9.897516	1.63	9.890204	4.35	0.109796	10
.787883	2.70	.897418	1.63	.890465	4.33	.109535	9
.788045	2.72	.897320	1.63	.890725	4.35	.109275	8
.788208	2.70	.897222	1.65	.890986	4.35	.109014	7
.788370	2.70	.897123	1.63	.891247	4.33	.108753	6
9.788532	2.70	9.897025	1.65	9.891507	4.35	0.108493	5
.788694	2.70	.896926	1.63	.891768	4.33	.108232	4
.788856	2.70	.896828	1.65	.892028	4.35	.107972	3
.789018	2.70	.896729	1.63	.892289	4.33	.107711	2
.789180	2.70	.896631	1.65	.892549	4.35	.107451	1
9.789342		9.896532		9.892810		0.107190	0
Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M.

M.	Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
0	9.789342	2.70	9.896532	1.65	9.892810	4.33	0.107190	60
1	.789504	2.68	.896433	1.63	.893070	4.35	.106930	59
2	.789665	2.70	.896335	1.65	.893331	4.33	.106669	58
3	.789827	2.68	.896236	1.65	.893591	4.33	.106409	57
4	.789988	2.68	.896137	1.65	.893851	4.33	.106149	56
5	9.790149	2.68	9.896038	1.65	9.894111	4.35	0.105889	55
6	.790310	2.68	.895939	1.65	.894372	4.33	.105628	54
7	.790471	2.68	.895840	1.65	.894632	4.33	.105368	53
8	.790632	2.68	.895741	1.67	.894892	4.33	.105108	52
9	.790793	2.68	.895641	1.65	.895152	4.33	.104848	51
10	9.790954	2.68	9.895542	1.65	9.895412	4.33	0.104588	50
11	.791115	2.67	.895443	1.67	.895672	4.33	.104328	49
12	.791275	2.68	.895343	1.65	.895932	4.33	.104068	48
13	.791436	2.67	.895244	1.65	.896192	4.33	.103808	47
14	.791596	2.68	.895145	1.67	.896452	4.33	.103548	46
15	9.791757	2.67	9.895045	1.67	9.896712	4.32	0.103288	45
16	.791917	2.67	.894945	1.65	.896971	4.33	.103029	44
17	.792077	2.67	.894846	1.67	.897231	4.33	.102769	43
18	.792237	2.67	.894746	1.67	.897491	4.33	.102509	42
19	.792397	2.67	.894646	1.67	.897751	4.32	.102249	41
20	9.792557	2.65	9.894546	1.67	9.898010	4.33	0.101990	40
21	.792716	2.67	.894446	1.67	.898270	4.33	.101730	39
22	.792876	2.65	.894346	1.67	.898530	4.32	.101470	38
23	.793035	2.67	.894246	1.67	.898789	4.33	.101211	37
24	.793195	2.65	.894146	1.67	.899049	4.32	.100951	36
25	9.793354	2.67	9.894046	1.67	9.899308	4.33	0.100692	35
26	.793514	2.65	.893946	1.67	.899568	4.32	.100432	34
27	.793673	2.65	.893846	1.68	.899827	4.33	.100173	33
28	.793832	2.65	.893745	1.67	.900087	4.32	.099913	32
29	.793991	2.65	.893645	1.68	.900346	4.32	.099654	31
30	9.794150	2.63	9.893544	1.67	9.900605	4.32	0.099395	30
31	.794308	2.65	.893444	1.68	.900864	4.33	.099136	29
32	.794467	2.65	.893343	1.67	.901124	4.32	.098876	28
33	.794626	2.63	.893243	1.68	.901383	4.32	.098617	27
34	.794784	2.63	.893142	1.68	.901642	4.32	.098358	26
35	9.794942	2.65	9.893041	1.68	9.901901	4.32	0.098099	25
36	.795101	2.63	.892940	1.68	.902160	4.33	.097840	24
37	.795259	2.63	.892839	1.67	.902420	4.32	.097580	23
38	.795417	2.63	.892739	1.68	.902679	4.32	.097321	22
39	.795575	2.63	.892638	1.70	.902938	4.32	.097062	21
40	9.795733	2.63	9.892536	1.68	9.903197	4.32	0.096803	20
41	.795891	2.63	.892435	1.68	.903456	4.30	.096544	19
42	.796049	2.62	.892334	1.68	.903714	4.32	.096286	18
43	.796206	2.63	.892233	1.68	.903973	4.32	.096027	17
44	.796364	2.62	.892132	1.70	.904232	4.32	.095768	16
45	9.796521	2.63	9.892030	1.68	9.904491	4.32	0.095509	15
46	.796679	2.62	.891929	1.70	.904750	4.30	.095250	14
47	.796836	2.62	.891827	1.68	.905008	4.32	.094992	13
48	.796993	2.62	.891726	1.70	.905267	4.32	.094733	12
49	.797150	2.62	.891624	1.68	.905526	4.32	.094474	11
50	9.797307	2.62	9.891523	1.70	9.905785	4.30	0.094215	10
51	.797464	2.62	.891421	1.70	.906043	4.32	.093957	9
52	.797621	2.60	.891319	1.70	.906302	4.30	.093698	8
53	.797777	2.62	.891217	1.70	.906560	4.32	.093440	7
54	.797934	2.62	.891115	1.70	.906819	4.30	.093181	6
55	9.798091	2.60	9.891013	1.70	9.907077	4.32	0.092923	5
56	.798247	2.60	.890911	1.70	.907336	4.30	.092664	4
57	.798403	2.62	.890809	1.70	.907594	4.32	.092406	3
58	.798560	2.60	.890707	1.70	.907853	4.30	.092147	2
59	.798716	2.60	.890605	1.70	.908111	4.30	.091889	1
60	9.798872		9.890503		9.908369		0.091631	0
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M

M.	Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
0	9.798872	2.60	9.890503	1.72	9.908369	4.32	0.091631	60
1	.799028	2.60	.890400	1.70	.908628	4.30	.091372	59
2	.799184	2.58	.890298	1.72	.908886	4.30	.091114	58
3	.799339	2.60	.890195	1.70	.909144	4.30	.090856	57
4	.799495	2.60	.890093	1.72	.909402	4.30	.090598	56
5	9.799651	2.58	9.889990	1.70	9.909660	4.30	0.090340	55
6	.799806	2.60	.889888	1.72	.909918	4.32	.090082	54
7	.799962	2.58	.889785	1.72	.910177	4.30	.089823	53
8	.800117	2.58	.889682	1.72	.910435	4.30	.089565	52
9	.800272	2.58	.889579	1.70	.910693	4.30	.089307	51
10	9.800427	2.58	9.889477	1.72	9.910951	4.30	0.089049	50
11	.800582	2.58	.889374	1.72	.911209	4.30	.088791	49
12	.800737	2.58	.889271	1.72	.911467	4.30	.088533	48
13	.800892	2.58	.889168	1.73	.911725	4.28	.088275	47
14	.801047	2.57	.889064	1.72	.911982	4.30	.088018	46
15	9.801201	2.58	9.888961	1.72	9.912240	4.30	0.087760	45
16	.801356	2.58	.888858	1.72	.912498	4.30	.087502	44
17	.801511	2.57	.888755	1.73	.912756	4.30	.087244	43
18	.801665	2.57	.888651	1.72	.913014	4.28	.086986	42
19	.801819	2.57	.888548	1.73	.913271	4.30	.086729	41
20	9.801973	2.58	9.888444	1.72	9.913529	4.30	0.086471	40
21	.802128	2.57	.888341	1.73	.913787	4.28	.086213	39
22	.802282	2.57	.888237	1.72	.914044	4.30	.085956	38
23	.802436	2.55	.888134	1.73	.914302	4.30	.085698	37
24	.802589	2.57	.888030	1.73	.914560	4.28	.085440	36
25	9.802743	2.57	9.887926	1.73	9.914817	4.30	0.085183	35
26	.802897	2.55	.887822	1.73	.915075	4.28	.084925	34
27	.803050	2.57	.887718	1.73	.915332	4.30	.084668	33
28	.803204	2.55	.887614	1.73	.915590	4.28	.084410	32
29	.803357	2.57	.887510	1.73	.915847	4.28	.084153	31
30	9.803511	2.55	9.887406	1.73	9.916104	4.30	0.083896	30
31	.803664	2.55	.887302	1.73	.916362	4.28	.083638	29
32	.803817	2.55	.887198	1.75	.916619	4.30	.083381	28
33	.803970	2.55	.887093	1.73	.916877	4.28	.083123	27
34	.804123	2.55	.886989	1.73	.917134	4.28	.082866	26
35	9.804276	2.53	9.886885	1.75	9.917391	4.28	0.082609	25
36	.804428	2.55	.886780	1.73	.917648	4.30	.082352	24
37	.804581	2.55	.886676	1.75	.917906	4.28	.082094	23
38	.804734	2.53	.886571	1.75	.918163	4.28	.081837	22
39	.804886	2.55	.886466	1.73	.918420	4.28	.081580	21
40	9.805039	2.53	9.886362	1.75	9.918677	4.28	0.081323	20
41	.805191	2.53	.886257	1.75	.918934	4.28	.081066	19
42	.805343	2.53	.886152	1.75	.919191	4.28	.080809	18
43	.805495	2.53	.886047	1.75	.919448	4.28	.080552	17
44	.805647	2.53	.885942	1.75	.919705	4.28	.080295	16
45	9.805799	2.53	9.885837	1.75	9.919962	4.28	0.080038	15
46	.805951	2.53	.885732	1.75	.920219	4.28	.079781	14
47	.806103	2.52	.885627	1.75	.920476	4.28	.079524	13
48	.806254	2.53	.885522	1.77	.920733	4.28	.079267	12
49	.806406	2.52	.885416	1.75	.920990	4.28	.079010	11
50	9.806557	2.53	9.885311	1.77	9.921247	4.27	0.078753	10
51	.806709	2.52	.885205	1.75	.921503	4.28	.078497	9
52	.806860	2.52	.885100	1.77	.921760	4.28	.078240	8
53	.807011	2.53	.884994	1.75	.922017	4.28	.077983	7
54	.807163	2.52	.884889	1.77	.922274	4.27	.077726	6
55	9.807314	2.52	9.884783	1.77	9.922530	4.28	0.077470	5
56	.807465	2.50	.884677	1.75	.922787	4.28	.077213	4
57	.807615	2.52	.884572	1.77	.923044	4.27	.076956	3
58	.807766	2.52	.884466	1.77	.923300	4.28	.076700	2
59	.807917	2.50	.884360	1.77	.923557	4.28	.076443	1
60	9.808067		9.884254		9.923814		0.076186	0
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M.

M.	Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
0	9.808067	2.52	9.884254	1.77	9.923814	4.27	0.076186	60
1	.808218	2.50	.884148	1.77	.924070	4.28	.075930	59
2	.808368	2.52	.884042	1.77	.924327	4.27	.075673	58
3	.808519	2.50	.883936	1.78	.924583	4.28	.075417	57
4	.808669	2.50	.883829	1.77	.924840	4.27	.075160	56
5	9.808819	2.50	9.883723	1.77	9.925096	4.27	0.074904	55
6	.808969	2.50	.883617	1.78	.925352	4.28	.074648	54
7	.809119	2.50	.883510	1.77	.925609	4.27	.074391	53
8	.809269	2.50	.883404	1.78	.925865	4.28	.074135	52
9	.809419	2.50	.883297	1.77	.926122	4.27	.073878	51
10	9.809569	2.48	9.883191	1.78	9.926378	4.27	0.073622	50
11	.809718	2.50	.883084	1.78	.926634	4.27	.073366	49
12	.809868	2.48	.882977	1.77	.926890	4.28	.073110	48
13	.810017	2.50	.882871	1.78	.927147	4.27	.072853	47
14	.810167	2.48	.882764	1.78	.927403	4.27	.072597	46
15	9.810316	2.48	9.882657	1.78	9.927659	4.27	0.072341	45
16	.810465	2.48	.882550	1.78	.927915	4.27	.072085	44
17	.810614	2.48	.882443	1.78	.928171	4.27	.071829	43
18	.810763	2.48	.882336	1.78	.928427	4.28	.071573	42
19	.810912	2.48	.882229	1.80	.928684	4.27	.071316	41
20	9.811061	2.48	9.882121	1.78	9.928940	4.27	0.071060	40
21	.811210	2.47	.882014	1.78	.929196	4.27	.070804	39
22	.811358	2.48	.881907	1.80	.929452	4.27	.070548	38
23	.811507	2.47	.881799	1.78	.929708	4.27	.070292	37
24	.811655	2.48	.881692	1.80	.929964	4.27	.070036	36
25	9.811804	2.47	9.881584	1.78	9.930220	4.25	0.069780	35
26	.811952	2.47	.881477	1.80	.930475	4.27	.069525	34
27	.812100	2.47	.881369	1.80	.930731	4.27	.069269	33
28	.812248	2.47	.881261	1.80	.930987	4.27	.069013	32
29	.812396	2.47	.881153	1.78	.931243	4.27	.068757	31
30	9.812544	2.47	9.881046	1.80	9.931499	4.27	0.068501	30
31	.812692	2.47	.880938	1.80	.931755	4.25	.068245	29
32	.812840	2.47	.880830	1.80	.932010	4.27	.067990	28
33	.812988	2.45	.880722	1.82	.932266	4.27	.067734	27
34	.813135	2.47	.880613	1.80	.932522	4.27	.067478	26
35	9.813283	2.45	9.880505	1.80	9.932778	4.25	0.067222	25
36	.813430	2.47	.880397	1.80	.933033	4.27	.066967	24
37	.813578	2.45	.880289	1.82	.933289	4.27	.066711	23
38	.813725	2.45	.880180	1.80	.933545	4.25	.066455	22
39	.813872	2.45	.880072	1.82	.933800	4.27	.066200	21
40	9.814019	2.45	9.879963	1.80	9.934056	4.25	0.065944	20
41	.814166	2.45	.879855	1.82	.934311	4.27	.065689	19
42	.814313	2.45	.879746	1.82	.934567	4.25	.065433	18
43	.814460	2.45	.879637	1.80	.934822	4.27	.065178	17
44	.814607	2.43	.879529	1.82	.935078	4.25	.064922	16
45	9.814753	2.45	9.879420	1.82	9.935333	4.27	0.064667	15
46	.814900	2.43	.879311	1.82	.935589	4.25	.064411	14
47	.815046	2.45	.879202	1.82	.935844	4.27	.064156	13
48	.815193	2.43	.879093	1.82	.936100	4.25	.063900	12
49	.815339	2.43	.878984	1.82	.936355	4.27	.063645	11
50	9.815485	2.45	9.878875	1.82	9.936611	4.25	0.063389	10
51	.815632	2.43	.878766	1.83	.936866	4.25	.063134	9
52	.815778	2.43	.878656	1.82	.937121	4.27	.062879	8
53	.815924	2.42	.878547	1.82	.937377	4.25	.062623	7
54	.816069	2.43	.878438	1.83	.937632	4.25	.062368	6
55	9.816215	2.43	9.878328	1.82	9.937887	4.25	0.062113	5
56	.816361	2.43	.878219	1.83	.938142	4.27	.061858	4
57	.816507	2.42	.878109	1.83	.938398	4.25	.061602	3
58	.816652	2.43	.877999	1.82	.938653	4.25	.061347	2
59	.816798	2.42	.877890	1.83	.938908	4.25	.061092	1
60	9.816943		9.877780		9.939163		0.060837	0
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M.

M.	Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
0	9.816943	2.42	9.877780	1.83	9.939163	4.25	0.060837	60
1	.817088	2.42	.877670	1.83	.939418	4.25	.060582	59
2	.817233	2.43	.877560	1.83	.939673	4.25	.060327	58
3	.817379	2.42	.877450	1.83	.939928	4.25	.060072	57
4	.817524	2.40	.877340	1.83	.940183	4.27	.059817	56
5	9.817668	2.42	9.877230	1.83	9.940439	4.25	0.059561	55
6	.817813	2.42	.877120	1.83	.940694	4.25	.059306	54
7	.817958	2.42	.877010	1.85	.940949	4.25	.059051	53
8	.818103	2.40	.876899	1.83	.941204	4.25	.058796	52
9	.818247	2.42	.876789	1.85	.941459	4.23	.058541	51
10	9.818392	2.40	9.876678	1.83	9.941713	4.25	0.058287	50
11	.818536	2.42	.876568	1.85	.941968	4.25	.058032	49
12	.818681	2.40	.876457	1.83	.942223	4.25	.057777	48
13	.818825	2.40	.876347	1.85	.942478	4.25	.057522	47
14	.818969	2.40	.876236	1.85	.942733	4.25	.057267	46
15	9.819113	2.40	9.876125	1.85	9.942988	4.25	0.057012	45
16	.819257	2.40	.876014	1.83	.943243	4.25	.056757	44
17	.819401	2.40	.875904	1.85	.943498	4.23	.056502	43
18	.819545	2.40	.875793	1.85	.943752	4.25	.056248	42
19	.819689	2.38	.875682	1.85	.944007	4.25	.055993	41
20	9.819832	2.40	9.875571	1.87	9.944262	4.25	0.055738	40
21	.819976	2.40	.875459	1.85	.944517	4.23	.055483	39
22	.820120	2.38	.875348	1.85	.944771	4.25	.055229	38
23	.820263	2.38	.875237	1.85	.945026	4.25	.054974	37
24	.820406	2.40	.875126	1.87	.945281	4.23	.054719	36
25	9.820550	2.38	9.875014	1.85	9.945535	4.25	0.054465	35
26	.820693	2.38	.874903	1.87	.945790	4.25	.054210	34
27	.820836	2.38	.874791	1.85	.946045	4.23	.053955	33
28	.820979	2.38	.874680	1.87	.946299	4.25	.053701	32
29	.821122	2.38	.874568	1.87	.946554	4.23	.053446	31
30	9.821265	2.37	9.874456	1.87	9.946808	4.25	0.053192	30
31	.821407	2.38	.874344	1.87	.947063	4.25	.052937	29
32	.821550	2.38	.874232	1.85	.947318	4.23	.052682	28
33	.821693	2.37	.874121	1.87	.947572	4.25	.052428	27
34	.821835	2.37	.874009	1.88	.947827	4.23	.052173	26
35	9.821977	2.38	9.873896	1.87	9.948081	4.23	0.051919	25
36	.822120	2.37	.873784	1.87	.948335	4.25	.051665	24
37	.822262	2.37	.873672	1.87	.948590	4.23	.051410	23
38	.822404	2.37	.873560	1.87	.948844	4.25	.051156	22
39	.822546	2.37	.873448	1.88	.949099	4.23	.050901	21
40	9.822688	2.37	9.873335	1.87	9.949353	4.25	0.050647	20
41	.822830	2.37	.873223	1.88	.949608	4.23	.050392	19
42	.822972	2.37	.873110	1.87	.949862	4.23	.050138	18
43	.823114	2.35	.872998	1.88	.950116	4.25	.049884	17
44	.823255	2.37	.872885	1.88	.950371	4.23	.049629	16
45	9.823397	2.37	9.872772	1.88	9.950625	4.23	0.049375	15
46	.823539	2.35	.872659	1.87	.950879	4.23	.049121	14
47	.823680	2.35	.872547	1.88	.951133	4.25	.048867	13
48	.823821	2.37	.872434	1.88	.951388	4.23	.048612	12
49	.823963	2.35	.872321	1.88	.951642	4.23	.048358	11
50	9.824104	2.35	9.872208	1.88	9.951896	4.23	0.048104	10
51	.824245	2.35	.872095	1.90	.952150	4.25	.047850	9
52	.824386	2.35	.871981	1.88	.952405	4.23	.047595	8
53	.824527	2.35	.871868	1.88	.952659	4.23	.047341	7
54	.824668	2.33	.871755	1.90	.952913	4.23	.047087	6
55	9.824808	2.35	9.871641	1.88	9.953167	4.23	0.046833	5
56	.824949	2.35	.871528	1.90	.953421	4.23	.046579	4
57	.825090	2.33	.871414	1.88	.953675	4.23	.046325	3
58	.825230	2.35	.871301	1.90	.953929	4.23	.046071	2
59	.825371	2.33	.871187	1.90	.954183	4.23	.045817	1
60	9.825511		9.871073		9.954437		0.045563	0
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M.

M.	Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
0	9.825511	2.33	9.871073	1.88	9.954437	4.23	0.045563	60
1	.825651	2.33	.870960	1.90	.954691	4.25	.045309	59
2	.825791	2.33	.870846	1.90	.954946	4.23	.045054	58
3	.825931	2.33	.870732	1.90	.955200	4.23	.044800	57
4	.826071	2.33	.870618	1.90	.955454	4.23	.044546	56
5	9.826211	2.33	9.870504	1.90	9.955708	4.22	0.044292	55
6	.826351	2.33	.870390	1.90	.955961	4.23	.044039	54
7	.826491	2.33	.870276	1.92	.956215	4.23	.043785	53
8	.826631	2.32	.870161	1.90	.956469	4.23	.043531	52
9	.826770	2.33	.870047	1.90	.956723	4.23	.043277	51
10	9.826910	2.32	9.869933	1.92	9.956977	4.23	0.043023	50
11	.827049	2.33	.869818	1.90	.957231	4.23	.042769	49
12	.827189	2.32	.869704	1.92	.957485	4.23	.042515	48
13	.827328	2.32	.869589	1.92	.957739	4.23	.042261	47
14	.827467	2.32	.869474	1.90	.957993	4.23	.042007	46
15	9.827606	2.32	9.869360	1.92	9.958247	4.22	0.041753	45
16	.827745	2.32	.869245	1.92	.958500	4.23	.041500	44
17	.827884	2.32	.869130	1.92	.958754	4.23	.041246	[redacted]
18	.828023	2.32	.869015	1.92	.959008	4.23	.040992	42
19	.828162	2.32	.868900	1.92	.959262	4.23	.040738	41
20	9.828301	2.30	9.868785	1.92	9.959516	4.22	0.040484	40
21	.828439	2.32	.868670	1.92	.959769	4.23	.040231	39
22	.828578	2.30	.868555	1.92	.960023	4.23	.039977	38
23	.828716	2.32	.868440	1.93	.960277	4.22	.039723	37
24	.828855	2.30	.868324	1.92	.960530	4.23	.039470	36
25	9.828993	2.30	9.868209	1.93	9.960784	4.23	0.039216	35
26	.829131	2.30	.868093	1.92	.961038	4.23	.038962	34
27	.829269	2.30	.867978	1.93	.961292	4.22	.038708	33
28	.829407	2.30	.867862	1.92	.961545	4.23	.038455	32
29	.829545	2.30	.867747	1.93	.961799	4.22	.038201	31
30	9.829683	2.30	9.867631	1.93	9.962052	4.23	0.037948	30
31	.829821	2.30	.867515	1.93	.962306	4.23	.037694	29
32	.829959	2.30	.867399	1.93	.962560	4.22	.037440	28
33	.830097	2.28	.867283	1.93	.962813	4.23	.037187	27
34	.830234	2.30	.867167	1.93	.963067	4.22	.036933	26
35	9.830372	2.28	9.867051	1.93	9.963320	4.23	0.036680	25
36	.830509	2.28	.866935	1.93	.963574	4.23	.036426	24
37	.830646	2.30	.866819	1.93	.963828	4.22	.036172	23
38	.830784	2.28	.866703	1.95	.964081	4.23	.035919	22
39	.830921	2.28	.866586	1.93	.964335	4.22	.035665	21
40	9.831058	2.28	9.866470	1.95	9.964588	4.23	0.035412	20
41	.831195	2.28	.866353	1.93	.964842	4.22	.035158	19
42	.831332	2.28	.866237	1.95	.965095	4.23	.034905	18
43	.831469	2.28	.866120	1.93	.965349	4.22	.034651	17
44	.831606	2.27	.866004	1.95	.965602	4.22	.034398	16
45	9.831742	2.28	9.865887	1.95	9.965855	4.23	0.034145	15
46	.831879	2.27	.865770	1.95	.966109	4.22	.033891	14
47	.832015	2.28	.865653	1.95	.966362	4.23	.033638	13
48	.832152	2.27	.865536	1.95	.966616	4.22	.033384	12
49	.832288	2.28	.865419	1.95	.966869	4.23	.033131	11
50	9.832425	2.27	9.865302	1.95	9.967123	4.22	0.032877	10
51	.832561	2.27	.865185	1.95	.967376	4.22	.032624	9
52	.832697	2.27	.865068	1.97	.967629	4.23	.032371	8
53	.832833	2.27	.864950	1.95	.967883	4.22	.032117	7
54	.832969	2.27	.864833	1.95	.968136	4.22	.031864	6
55	9.833105	2.27	9.864716	1.97	9.968389	4.23	0.031611	5
56	.833241	2.27	.864598	1.95	.968643	4.22	.031357	4
57	.833377	2.25	.864481	1.97	.968896	4.22	.031104	3
58	.833512	2.27	.864363	1.97	.969149	4.23	.030851	2
59	.833648	2.25	.864245	1.97	.969403	4.22	.030597	1
60	9.833783		9.864127		9.969656		0.030344	0
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M.

M.	Sin.	D. 1".	Cos.	D. 1".	Tan.	D. 1".	Cot.	
0	9.833783	2.27	9.864127	1.95	9.969656	4.22	0.030344	60
1	.833919	2.25	.864010	1.97	.969909	4.22	.030091	59
2	.834054	2.25	.863892	1.97	.970162	4.23	.029838	58
3	.834189	2.27	.863774	1.97	.970416	4.22	.029584	57
4	.834325	2.25	.863656	1.97	.970669	4.22	.029331	56
5	9.834460	2.25	9.863538	1.98	9.970922	4.22	0.029078	55
6	.834595	2.25	.863419	1.97	.971175	4.23	.028825	54
7	.834730	2.25	.863301	1.97	.971429	4.22	.028571	53
8	.834865	2.23	.863183	1.98	.971682	4.22	.028318	52
9	.834999	2.25	.863064	1.97	.971935	4.22	.028065	51
10	9.835134	2.25	9.862946	1.98	9.972188	4.22	0.027812	50
11	.835269	2.23	.862827	1.97	.972441	4.23	.027559	49
12	.835403	2.25	.862709	1.98	.972695	4.22	.027305	48
13	.835538	2.23	.862590	1.98	.972948	4.22	.027052	47
14	.835672	2.25	.862471	1.97	.973201	4.22	.026799	46
15	9.835807	2.23	9.862353	1.98	9.973454	4.22	0.026546	45
16	.835941	2.23	.862234	1.98	.973707	4.22	.026293	44
17	.836075	2.23	.862115	1.98	.973960	4.22	.026040	43
18	.836209	2.23	.861996	1.98	.974213	4.22	.025787	42
19	.836343	2.23	.861877	1.98	.974466	4.23	.025534	41
20	9.836477	2.23	9.861758	2.00	9.974720	4.22	0.025280	40
21	.836611	2.23	.861638	1.98	.974973	4.22	.025027	39
22	.836745	2.22	.861519	1.98	.975226	4.22	.024774	38
23	.836878	2.23	.861400	2.00	.975479	4.22	.024521	37
24	.837012	2.23	.861280	1.98	.975732	4.22	.024268	36
25	9.837146	2.22	9.861161	2.00	9.975985	4.22	0.024015	35
26	.837279	2.22	.861041	1.98	.976238	4.22	.023762	34
27	.837412	2.23	.860922	2.00	.976491	4.22	.023509	33
28	.837546	2.22	.860802	2.00	.976744	4.22	.023256	32
29	.837679	2.22	.860682	2.00	.976997	4.22	.023003	31
30	9.837812	2.22	9.860562	2.00	9.977250	4.22	0.022750	30
31	.837945	2.22	.860442	2.00	.977503	4.22	.022497	29
32	.838078	2.22	.860322	2.00	.977756	4.22	.022244	28
33	.838211	2.22	.860202	2.00	.978009	4.22	.021991	27
34	.838344	2.22	.860082	2.00	.978262	4.22	.021738	26
35	9.838477	2.22	9.859962	2.00	9.978515	4.22	0.021485	25
36	.838610	2.20	.859842	2.02	.978768	4.22	.021232	24
37	.838742	2.22	.859721	2.00	.979021	4.22	.020979	23
38	.838875	2.20	.859601	2.02	.979274	4.22	.020726	22
39	.839007	2.22	.859480	2.00	.979527	4.22	.020473	21
40	9.839140	2.20	9.859360	2.02	9.979780	4.22	0.020220	20
41	.839272	2.20	.859239	2.00	.980033	4.22	.019967	19
42	.839404	2.20	.859119	2.02	.980286	4.20	.019714	18
43	.839536	2.20	.858998	2.02	.980538	4.22	.019462	17
44	.839668	2.20	.858877	2.02	.980791	4.22	.019209	16
45	9.839800	2.20	9.858756	2.02	9.981044	4.22	0.018956	15
46	.839932	2.20	.858635	2.02	.981297	4.22	.018703	14
47	.840064	2.20	.858514	2.02	.981550	4.22	.018450	13
48	.840196	2.20	.858393	2.02	.981803	4.22	.018197	12
49	.840328	2.18	.858272	2.02	.982056	4.22	.017944	11
50	9.840459	2.20	9.858151	2.03	9.982309	4.22	0.017691	10
51	.840591	2.18	.858029	2.02	.982562	4.20	.017438	9
52	.840722	2.20	.857908	2.03	.982814	4.22	.017186	8
53	.840854	2.18	.857786	2.02	.983067	4.22	.016933	7
54	.840985	2.18	.857665	2.03	.983320	4.22	.016680	6
55	9.841116	2.18	9.857543	2.02	9.983573	4.22	0.016427	5
56	.841247	2.18	.857422	2.03	.983826	4.22	.016174	4
57	.841378	2.18	.857300	2.03	.984079	4.22	.015921	3
58	.841509	2.18	.857178	2.03	.984332	4.20	.015668	2
59	.841640	2.18	.857056	2.03	.984584	4.22	.015416	1
60	9.841771		9.856934		9.984837		0.015163	0
	Cos.	D. 1".	Sin.	D. 1".	Cot.	D. 1".	Tan.	M.

M.	Sin.	D. 1″.	Cos.	D. 1″.	Tan.	D. 1″.	Cot.	
0	9.841771	2.18	9.856934	2.03	9.984837	4.22	0.015163	60
1	.841902	2.18	.856812	2.03	.985090	4.22	.014910	59
2	.842033	2.17	.856690	2.03	.985343	4.22	.014657	58
3	.842163	2.18	.856568	2.03	.985596	4.20	.014404	57
4	.842294	2.17	.856446	2.05	.985848	4.22	.014152	56
5	9.842424	2.18	9.856323	2.03	9.986101	4.22	0.013899	55
6	.842555	2.17	.856201	2.05	.986354	4.22	.013646	54
7	.842685	2.17	.856078	2.03	.986607	4.22	.013393	53
8	.842815	2.18	.855956	2.05	.986860	4.20	.013140	52
9	.842946	2.17	.855833	2.03	.987112	4.22	.012888	51
10	9.843076	2.17	9.855711	2.05	9.987365	4.22	0.012635	50
11	.843206	2.17	.855588	2.05	.987618	4.22	.012382	49
12	.843336	2.17	.855465	2.05	.987871	4.20	.012129	48
13	.843466	2.15	.855342	2.05	.988123	4.22	.011877	47
14	.843595	2.17	.855219	2.05	.988376	4.22	.011624	46
15	9.843725	2.17	9.855096	2.05	9.988629	4.22	0.011371	45
16	.843855	2.15	.854973	2.05	.988882	4.20	.011118	44
17	.843984	2.17	.854850	2.05	.989134	4.22	.010866	43
18	.844114	2.15	.854727	2.07	.989387	4.22	.010613	42
19	.844243	2.15	.854603	2.05	.989640	4.22	.010360	41
20	9.844372	2.17	9.854480	2.07	9.989893	4.20	0.010107	40
21	.844502	2.15	.854356	2.05	.990145	4.22	.009855	39
22	.844631	2.15	.854233	2.07	.990398	4.22	.009602	38
23	.844760	2.15	.854109	2.05	.990651	4.20	.009349	37
24	.844889	2.15	.853986	2.07	.990903	4.22	.009097	36
25	9.845018	2.15	9.853862	2.07	9.991156	4.22	0.008844	35
26	.845147	2.15	.853738	2.07	.991409	4.22	.008591	34
27	.845276	2.15	.853614	2.07	.991662	4.20	.008338	33
28	.845405	2.13	.853490	2.07	.991914	4.22	.008086	32
29	.845533	2.15	.853366	2.07	.992167	4.22	.007833	31
30	9.845662	2.13	9.853242	2.07	9.992420	4.20	0.007580	30
31	.845790	2.15	.853118	2.07	.992672	4.22	.007328	29
32	.845919	2.13	.852994	2.08	.992925	4.22	.007075	28
33	.846047	2.13	.852869	2.07	.993178	4.22	.006822	27
34	.846175	2.15	.852745	2.08	.993431	4.20	.006569	26
35	9.846304	2.13	9.852620	2.07	9.993683	4.22	0.006317	25
36	.846432	2.13	.852496	2.08	.993936	4.22	.006064	24
37	.846560	2.13	.852371	2.07	.994189	4.20	.005811	23
38	.846688	2.13	.852247	2.08	.994441	4.22	.005559	22
39	.846816	2.13	.852122	2.08	.994694	4.22	.005306	21
40	9.846944	2.12	9.851997	2.08	9.994947	4.20	0.005053	20
41	.847071	2.13	.851872	2.08	.995199	4.22	.004801	19
42	.847199	2.13	.851747	2.08	.995452	4.22	.004548	18
43	.847327	2.12	.851622	2.08	.995705	4.20	.004295	17
44	.847454	2.13	.851497	2.08	.995957	4.22	.004043	16
45	9.847582	2.12	9.851372	2.10	9.996210	4.22	0.003790	15
46	.847709	2.12	.851246	2.08	.996463	4.20	.003537	14
47	.847836	2.13	.851121	2.08	.996715	4.22	.003285	13
48	.847964	2.12	.850996	2.10	.996968	4.22	.003032	12
49	.848091	2.12	.850870	2.08	.997221	4.20	.002779	11
50	9.848218	2.12	9.850745	2.10	9.997473	4.22	0.002527	10
51	.848345	2.12	.850619	2.10	.997726	4.22	.002274	9
52	.848472	2.12	.850493	2.08	.997979	4.20	.002021	8
53	.848599	2.12	.850368	2.10	.998231	4.22	.001769	7
54	.848726	2.10	.850242	2.10	.998484	4.22	.001516	6
55	9.848852	2.12	9.850116	2.10	9.998737	4.20	0.001263	5
56	.848979	2.12	.849990	2.10	.998989	4.22	.001011	4
57	.849106	2.10	.849864	2.10	.999242	4.22	.000758	3
58	.849232	2.12	.849738	2.12	.999495	4.20	.000505	2
59	.849359	2.10	.849611	2.10	.999747	4.22	.000253	1
60	9.849485		9.849485		0.000000		0.000000	0
	Cos.	D. 1″.	Sin.	D. 1″.	Cot.	D. 1″.	Tan.	M.

TABLE 76. GIVING THE WEIGHTS OF DIFFERENT MATERIALS PER CUBIC FOOT[1]

MATERIAL	Weight per Cu. Ft.	
Ash timber	40	lbs.
Brick (pressed)	150	"
" (common building)	125	"
Cement (Portland)	75 to 90	"
" (Natural	50 to 56	"
Concrete 1:2:4 Mixture (Trap rock)	155	"
" (Gravel)	152	"
" (Limestone)	150	"
" (Sandstone)	145	"
" (Cinder)	110	"
" 1:3:6 Mixture (about 5 lbs. less)	—	"
Earth (common loam, loose and dry)	70	"
" (common loam, moist and rammed)	100	"
" (sand or gravel loose and dry)	100	"
" (sand or gravel rammed)	120	"
" (sand or gravel wet)	120	"
Hemlock timber	25	"
Hickory "	50	"
Iron (cast)	450	"
" (wrought)	480	"
Maple timber	50	"
Oak " (white)	48	"
" " (black)	40	"
Masonry (dressed granite or limestone)	165	"
" (mortar rubble)	155	"
" (dry ")	125	"
Pine (white)	25	"
" (northern yellow)	34	"
" (southern yellow)	40	"
Steel	490	"
Water	62.5	"

Miscellaneous Weights

1 bbl. Portland cement		376	lbs.
1 " natural	"	235	"
1 gal. water	"	8.345	"

[1] For weight of road rocks, see Tables 23a and 23b, page 233.

TABLE 77. GIVING MODULI OF ELASTICITY, WORKING STRESS AND ULTIMATE STRENGTH

MODULI OF ELASTICITY

Material	Lbs. per Sq. In.
Concrete	2,000,000
Hemlock	900,000
Iron (cast)	17,500,000
Iron (wrought)	29,000,000
Oak	1,500,000
Pine (white)	1,600,000
Pine (yellow)	1,600,000
Steel (medium)	30,000,000
Spruce	1,600,000

WORKING STRESSES IN LBS. PER SQUARE INCH

Material	Tension	Compression	Shear
Concrete	60	600	60 to 100
Hemlock	600	W. G.[1] 600 A. G.[2] 150	W. G. 100 A. G. 600
Iron (cast)	3,000	18,000	5,000
" (wrought)	10,000	8,000	8,000
Oak	1,200	W. G. 1,200 A. G. 500	W. G. 200 A. G. 1,000
Pine (white)	700	W. G. 700 A. G. 200	W. G. 100 A. G. 500
" (yellow)	1,200	W. G. 1,200 A. G. 350	W. G. 150 A. G. 1,250
Steel (medium)	12,000	12,000	12,000
Spuce	800	W G. 800 A. G. 200	W. G. 100 A. G. 750

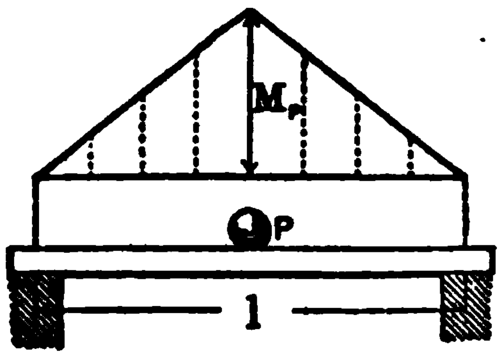
ULTIMATE STRENGTH IN LBS. PER SQUARE INCH

Material	Tension	Compression	Shear
Concrete	300	3,000	1300
Hemlock	6,000	W. G. 6,000 A. G. 600	W. G. 350 A. G. 2,500
Iron (cast)	18,000	90.000	20,000 to 30,000
" (wrought)	50,000	40,000	35,000 to 55,000
Oak	12,000	W. G 7,000 A. G. 2,000	W. G. 800 A. G. 4,000
Pine (white)	7,000	W G. 5,500 A. G. 700	W. G 400 A. G. 2,000
" (yellow)	12,000	W. G. 7,000 A. G. 1,400	W. G. 600 A. G. 5,000
Steel (medium)	60,000	60,000	50,000 to 70,000
Spruce	8,000	W. G. 6,000 A. G. 700	W. G. 400 A. G. 3,200

[1] W. G. — With Grain. [2] A. G. — Across Grain.

TABLE 78. UNIFORM BEAMS. MAXIMUM BENDING MOMENT AND DEFLECTIONS (SIMPLE CASES)

Case 1. Beam with ends free. Single concentrated load P in middle of span; weight of beam disregarded.



Concentrated Load in Center of span

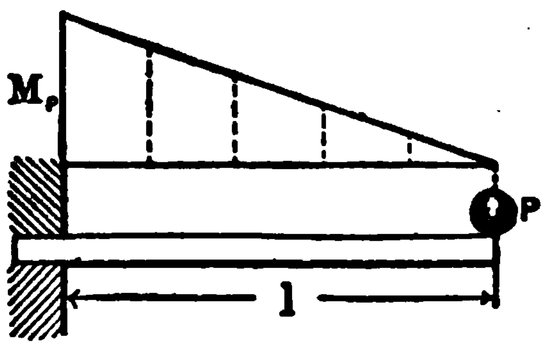
The maximum moment occurs at the center of the span.

$$M_p = \frac{Pl}{4}$$

The maximum deflection occurs at the center of the span.

$$D = \frac{Pl^3}{48\,EI}$$

Where D = the deflection in inches
P = load in pounds
l = span in inches
E = modulus of elasticity in lbs. per sq. inch
I = moment of inertia in inches^4
M_p = maximum moment in inch pounds.



Cantilever Beam

Case 2. Cantilever beam concentrated load P; weight of beam disregarded.

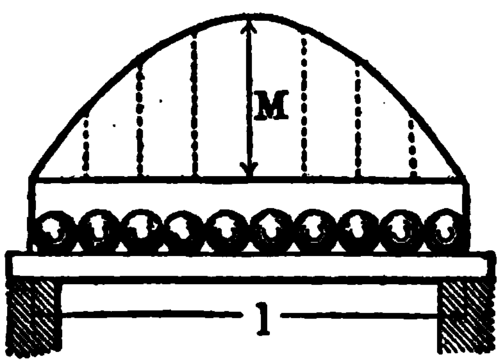
The maximum moment occurs at the support.

$$M_p = Pl$$

$$D = \frac{Pl^3}{3\,EI}$$

Case 3. Beam with ends free. Uniformly distributed load. The maximum moment occurs at the center of the span.

$$M = \frac{Wl}{8}$$



Uniform Load

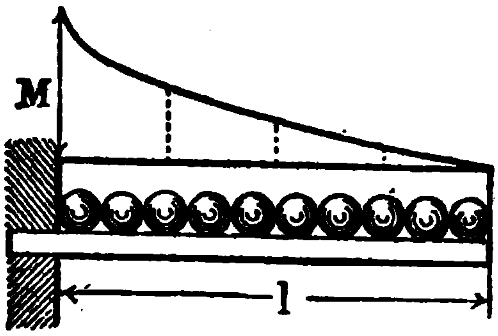
The maximum deflection occurs at the center of the span.

$$D = \frac{5}{384}\,\frac{Wl^3}{EI}$$

In these formulæ W equals the total uniformly distributed load.

Case 4. Cantilever beam. Uniform load W.

Maximum moment occurs at the point of support.



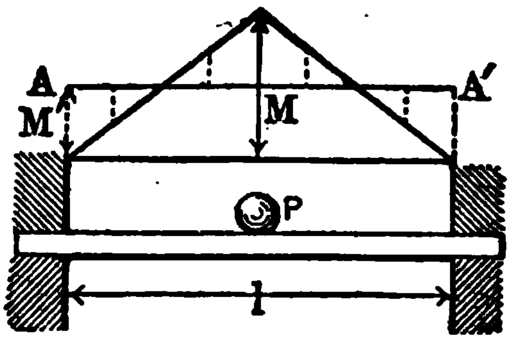
$$M = \frac{Wl}{2}$$

The maximum deflection occurs at the free end.

$$D = \frac{Wl^3}{8\,EI}$$

Case 5. Beam with fixed ends, concentrated load P in center of span; weight of beam disregarded.

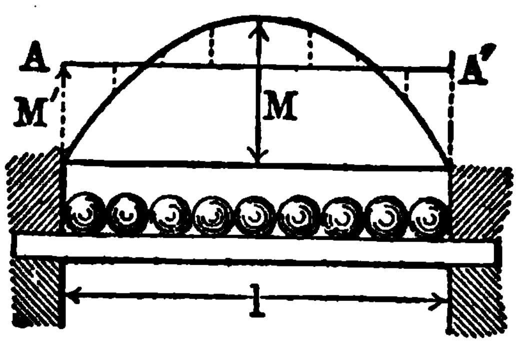
The maximum bending moment occurs at the points of support and at the middle of the beam.



$$M = \frac{Pl}{8}$$

$$D = \frac{Pl^3}{192\,EI}$$

Case 6. Beam with fixed ends and a uniformly distributed load. Maximum bending moment occurs at the supports.



$$M' = \frac{Wl}{12}$$

$$M = \frac{Wl}{24}$$

Maximum deflection

$$= \frac{Wl^3}{384\,EI}$$

Resisting Moment of a beam is expressed by the formula

$$M_r = \frac{pI}{e}$$

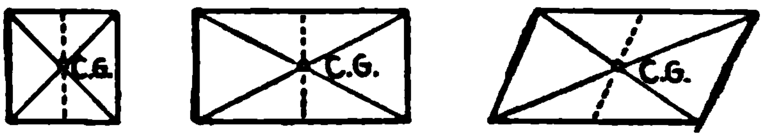
Where M_r = moment of resistance in inch pounds

p = maximum allowable fiber stress in lbs. per sq. inch.

I = moment of inertia of the beam in inches[4]

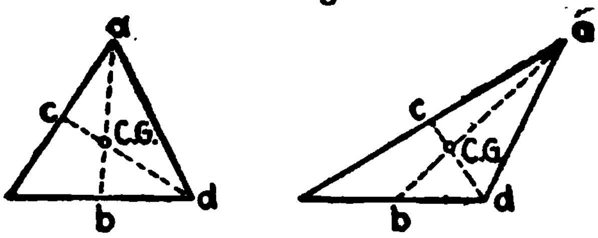
e = distance in inches from the neutral axis to the outer fiber

Table 79. Centers of Gravity of Ordinary Plane Figures



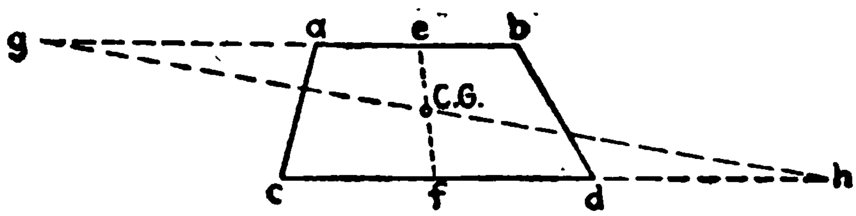
Squares, rectangles, parallelograms. Center of gravity is at the intersection of the diagonals or midway between the bases on a line drawn between the centers of those bases.

Triangles



Center of gravity is at the intersection of the medial lines *a b* and *c d;* a medial line is a line drawn from any apex to the middle of the opposite side The distance *b* (*C. G.*) = $\frac{1}{3}$ *a b;* that is, the center of gravity is on the medial line $\frac{1}{3}$ of the distance from the base to the apex.

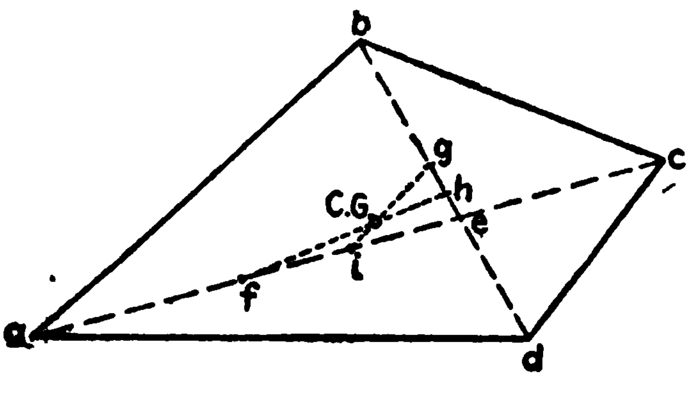
Trapezoid



Graphic Method. Prolong *b a* to *g*, making *a g* = *c d*. Prolong *c d* to *h*, making *d h* = *a b*. Connect *g h*. Bisect *a b* at *e*. Bisect *c d* at *f*. Connect *e f:* the intersection of *g h* and *e f* is the center of gravity.

$$\text{The distance } f\,(C.G.) = \frac{ef}{3} \times \frac{2\,ab + cd}{ab + cd}$$

Any Quadrilateral



Graphic Method. Draw the diagonals *a c* and *b d* intersecting at *e*.

Lay off *a f* = *e c*

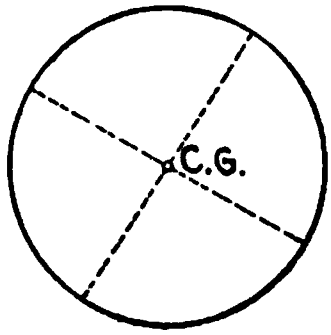
Lay off *b g* = *e d*

Bisect *e g* at *h*; bisect *e f* at *i*.

The intersection of *f h* and *g i* is the center of gravity of the figure.

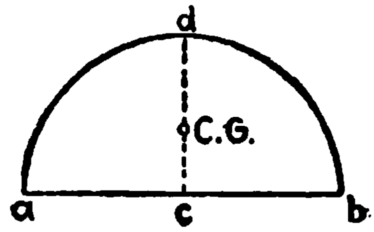
Circles

Center of gravity at the center



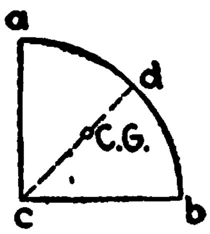
Semicircle

The center of gravity lies on the radius perpendicular to the diameter. The distance c $(C.G.)$ = radius × 0.4244



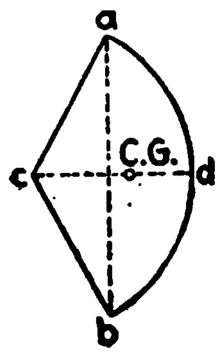
Quadrant

The center of gravity lies on the radius which bisects the $\angle\, a\, c\, b$. The distance c $(C.G.)$ = radius × 0.6002



Sector

The center of gravity lies on the radius bisecting the $\angle\, a\, c\, b$. The distance c $(C.G.) \equiv \frac{2}{3}$ radius × $\dfrac{\text{chord } a\,b}{\text{arc } a\,d\,b} = \dfrac{\text{radius}^2 \times \text{chord}}{3 \times \text{area}}$



Segment

The center of gravity lies on the perpendicular erected at the center of the chord ab.

The distance c $(C.G.) = \dfrac{\overline{\text{chord } ab}^3}{12 \times \text{area of segment}}$

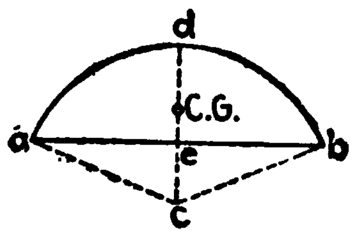
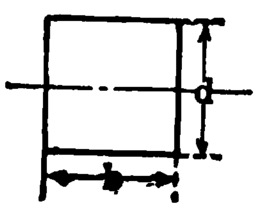
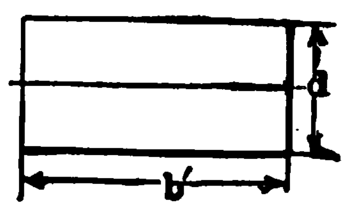


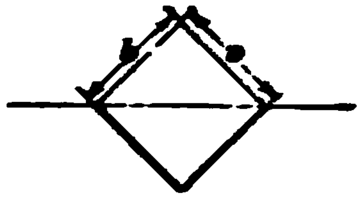
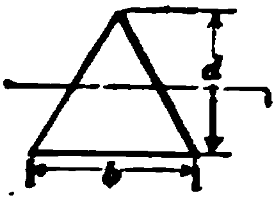
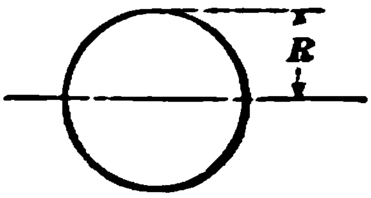
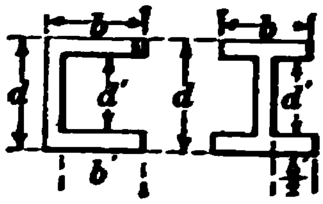
Table 80. Moments of Inertia of Simple Sections

I = Moment of Inertia

$$I = \frac{bd^3}{12}$$





 Square	$I = \frac{b^4}{12}$
 Triangles	$I = \frac{bd^3}{36}$
 Circles	$I = 0{\cdot}7854\, R^4$
	$I = \frac{bd^3 - b'd'^3}{12}$

APPENDIX A

TRAFFIC RULES AND REGULATIONS, STATE OF OHIO

FOREWORD

Inasmuch as Section 249 of the Cass Law, (G. C. 7246) directing the state highway commissioner to prepare and publish a set of traffic rules and regulations, is for the protection of life and limb, it is undoubtedly the most important section of the road laws of Ohio.

After much thought and investigation of rules and regulations governing traffic conditions in a number of states, we submit the following in as condensed form as explicitness will permit, having selected, as we believe, the better parts of such laws and regulations governing the traffic of other states and municipalities, and putting them into a code of rules and regulations that will fit, as nearly as may be, all conditions and localities requiring a code of regulations, which will at the same time govern traffic on all the highways of Ohio.

A cursory examination of these rules may lead many to the conclusion that unreasonable restrictions have been imposed, but we believe a thoughtful study of each section will reveal an effort on the part of the State Highway Department to furnish the public with a code of traffic regulations, permitting of the greatest amount of freedom consistent with *safety first*.

The original draft of the following regulations was submitted to Mr. W. A. Alsdorf, Secretary of the Ohio Good Roads Federation, Mr. Harry Gordon of Cincinnati, and Mr. Fred Caley of Cleveland, who carefully studied the entire code, section by section, and suggested many valuable and important changes.

We now put forth the result of our efforts with the belief that if the prescribed rules and regulations are followed, many embarrassing situations and distressing accidents may be averted.

CLINTON COWEN,
State Highway Commissioner.

ARTICLE I — DEFINITIONS

SEC. 1 — The term "vehicle" shall apply to a horse being rode or led, and to any conveyance except a baby carriage or street car.

SEC. 2 — The term "street car" shall apply to any conveyance confined to tracks.

SEC. 3 — The term "driver" shall apply to the rider, driver, or leader of a horse, a person who pushes, draws, propels, operates, or who is in charge of a vehicle.

SEC. 4 — The term "road" shall apply to that part of a street or public highway intended for vehicles.

SEC. 5. — The term "curb" shall apply to the boundary line of a road.

SEC. 6 — The term "sidewalk" shall apply to a path or walk intended for pedestrians.

SEC. 7 — The term "horse" shall apply to any draft animal or beast of burden.

SEC. 8 — The term "motor vehicle" shall apply to all vehicles propelled by power other than muscular, except a street car, traction engine, road roller, and police, fire or ambulance vehicles.

ARTICLE II — RESPECTIVE RIGHTS AND DUTIES OF DRIVERS AND PEDESTRIANS

SEC. 1 — Roads are primarily intended for vehicles, but pedestrians have the right to cross them in safety, and drivers shall exercise all possible care not to endanger them.

SEC. 2 — Pedestrians should observe the following precautions;

1st. Avoid interference with vehicular traffic, and to this end not step onto the road without first looking to see what is approaching:

2nd. Cross the road at right angles — at regular crossings where such exist, — and where a traffic officer is stationed, wait for his signal.

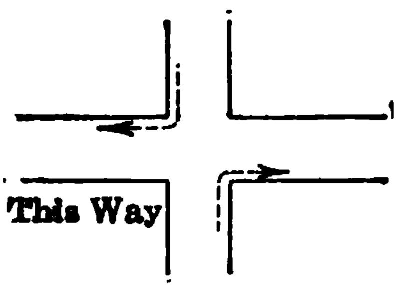
SEC. 3 — Pedestrians will aid in expediting traffic on side-walks by keeping to the right, and when stopping for any purpose by doing so on one side and out of the way of a crossing or driveway.

ARTICLE III — PASSING, TURNING, STOPPING, STANDING AND STARTING

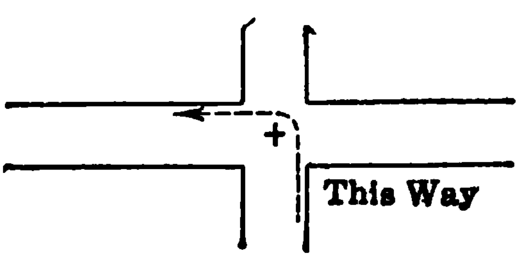
SEC. 1 — A vehicle meeting another shall keep to the right, so as to leave half the road free for the coming vehicle. (6310 G. C.)

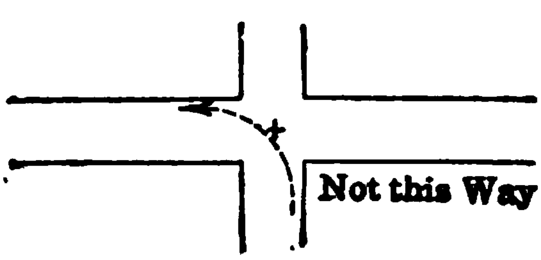
SEC. 2 — A vehicle overtaking another shall pass to the left, the front vehicle giving half the road to the rear vehicle. (6310 G. C.)

SEC. 3 — A vehicle turning into a road to the right shall turn the corner as near the right hand curb as practicable.

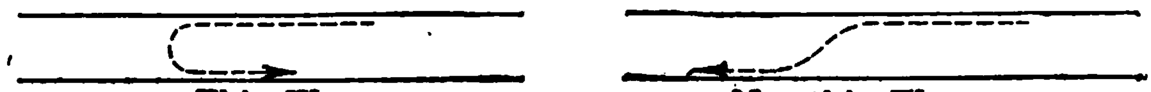


SEC. 4 — A vehicle turning into a road to the left shall pass around the point of intersection of the center lines of the two roads.





SEC. 5 — A vehicle crossing from one side to the other of a road shall head in the same direction as the traffic on that side of the road.



This Way Not this Way

SEC. 6 — On heavy traffic roads, slow moving vehicles shall keep close to the right hand curb so as to leave the center of the road clear for overtaking traffic — *the slower the speed the nearer the curb.*

SEC. 7 — A vehicle in passing around a circle shall keep to the right from entrance to exit.

SEC. 8 — A vehicle on a road divided longitudinally by a parkway, walk, rope or other obstruction, shall keep to the right of such division.

SEC. 9 — A vehicle shall not back to make a turn if by so doing it obstructs traffic, but shall go forward to a point where a turn can be made without backing.

SEC. 10 — A vehicle shall not follow another too closely for safety.

SEC. 11 — No vehicle shall stop in the road in such a position as to prevent the free passage of other vehicles in both directions at the same time.

SEC. 12 — A vehicle shall not pass a street car which has stopped to receive or discharge passengers at a less distance than ten feet, nor at a greater speed than six miles per hour. A vehicle shall come to a stop if necessary to prevent interference or injury to such passengers.

SEC. 13 — No horse or vehicle shall be driven, propelled or allowed to stand, on any side-walk except for purposes of crossing the same when necessary, and then only the shortest way from the road to the abutting premises.

SEC. 14 — No vehicle shall stop in such a way as to interfere with the passage of pedestrians at regular crossings, or within 10 feet of a fire plug.

SEC. 15 — No street car shall stop or stand within the intersection of any road.

ARTICLE IV — LOADS, LOADING, WIDTH OF TIRE, TRAILERS, ETC.

SEC. 1 — No traction engine or other vehicle whose wheels have tires equipped with lugs, spikes, chains or other projections seriously destructive to the surface, shall be driven over the road. (13421-12 G. C.)

SEC. 2 — No vehicle or load, the total width of which is greater than twelve feet, shall be operated or drawn over a road unless said greater width will leave one-half the road free for passing vehicles.

SEC. 3 — No more than thirty-four hundred pounds including weight of vehicle, shall be transported over a gravel, macadam or stone road in a vehicle having a tire less than three inches in width. (7477 G. C.)

SEC. 4 — For vehicles having tires three inches and over in width the load on any wheel per lineal inch of width of tire on any road shall not exceed six hundred pounds; and during such times as the road surface is soft, because of thawing or because of excessive rains, the load per lineal inch of width of tire on any wheel shall not exceed three hundred pounds on gravel or macadam roads.

SEC. 5 — Trailers used in hauling over the road shall be so connected that the wheels of no two will follow in the same tracks.

SEC. 6 — No vehicle carrying a load in excess of fifteen tons, including the weight of the vehicle, shall be moved over any road except under the written permission of the State Highway Commissioner.

ARTICLE V — SPEEDS

SEC. 1 — No motor vehicle shall operate on a road at a greater speed than:

8 miles per hour in the business or closely built up portions of a municipality;

15 miles per hour in other portions of a municipality;

20 miles per hour outside of municipalities. (12604 G. C.)

SEC. 2 — No vehicle shall operate on a road at a speed greater than is reasonable or proper or so as to endanger the property, life or limb of any person. (12603 G. C.)

SEC. 3 — No motor or other power vehicle carrying a weight in excess of four tons including a vehicle shall be operated upon any road at a speed greater than 15 miles per hour; and no such vehicle carrying a weight in excess of eight tons including the vehicle shall be operated at a speed greater than 6 miles per hour when such vehicle is equipped with iron or steel tires, nor greater than 12 miles per hour when the vehicle is equipped with tires of rubber or other similar substance.

SEC. 4 — No vehicle shall cross a road or make any turn at a dangerous speed.

SEC. 5 — Where "Danger" and "Go Slow" signs appear, the speed of any vehicles shall not exceed twelve miles per hour.

SEC. 6 — Trucks and heavy wagons shall not be driven recklessly so as to endanger the public.

SEC. 7 — No vehicle shall emerge from an alley, stable, garage or any private drive or entrance faster than a walk or six miles per hour.

SEC. 8 — A vehicle upon approaching a cross road shall slow down sufficiently to prevent any danger from meeting other vehicles on the cross road.

SEC. 9 — No person shall race any horse or motor vehicle on a road whether the running, racing or trotting be for trial or speed or for the purpose of passing another horse or vehicle.

SEC. 10 — A motor vehicle, road roller or traction engine shall slow down when approaching a horse, if the horse appears to be frightened, and if the driver of the horse shall signal the driver of the vehicle the latter shall be brought to a stop, and if the circumstances require it, the engine shall be stopped, provided such signal

be given in good faith and under circumstances of necessity. Such vehicle shall remain stationary so long as may be reasonable to allow such horse to pass. (12605 G. C.)

SEC. 11 — In case of injury or damage to person or property, due to the operation of vehicle, the operator or driver of said vehicle shall stop, and, upon request of the person injured or any one present, give his name and address and that of the owner of the vehicle. (12606 G. C.)

ARTICLE VI — SIGNALS, HORNS, SIGNS AND NOISES

SEC. 1 — All motor vehicles and bicycles shall be equipped with a suitable bell or horn for signalling. (12614 G. C.)

SEC. 2 — When a vehicle is slowing up or stopping, the driver shall give a timely signal to those in the rear, by raising the arm or whip vertically (preferably) or horizontally or by some other unmistakable manner.

SEC. 3 — When about to turn either from a standstill or while in motion, the driver of a vehicle shall give timely signal by hand or whip or in some other unmistakable manner, to indicate the direction of the turn. *This is especially important when turning to the left.*

SEC. 4 — Before a vehicle is backed, the driver shall give timely warning.

SEC. 5 — Sound signals are prohibited except for necessary warning, and must be reserved for that purpose. Signals shall not be sounded by unauthorized persons on standing vehicles.

SEC. 6 — All signs, signals and orders of a traffic officer shall be promptly complied with.

SEC. 7 — Every driver of a motor vehicle shall give a timely warning when overtaking a person or vehicle on a road or when approaching a crossing or curve where the sight of approaching vehicles may be obscured.

SEC. 8 — No vehicle shall be so loaded as to cause an objectionable or unnecessary noise by parts of the load striking together or upon the vehicle.

SEC. 9 — The use between the hours of 8 P. M. and 6 A. M. of the muffler cut-out or the production of any other unnecessarily loud noise on any vehicle, is prohibited within 100 yards of any residence or within such distance as might seriously disturb the inhabitants of such residence.

SEC. 10 — No vehicle shall pass over any road which is closed against traffic to be repaired or constructed. A suitable sign or barricade shall be considered as sufficient evidence that such road is closed. (13421-9 G. C.)

ARTICLE VII — RIGHT OF WAY

SEC. 1 — Every driver of a vehicle approaching the intersection of a road where a traffic officer is not stationed, shall *grant the right of way at such intersection to any vehicle approaching from his right.*

SEC. 2 — A vehicle in front of a street car shall immediately turn out upon the signal of the operator of the car.

SEC. 3 — A vehicle shall not so occupy any road as to obstruct traffic.

SEC. 4 — When in the performance of duty, the following vehicles shall have the right of way: Police, Fire, Fire Patrol, Ambulance, U. S. Mail; also the militia.

SEC. 5 — During blockades and stoppages a clear space shall be kept open between all street cars at crossings.

SEC. 6 — Pedestrians about to get on, or just having been discharged from a street car shall have the right of way and vehicles shall come to a stop when necessary to give such pedestrians the right of way.

ARTICLE VIII — LIGHTS

SEC. 1 — Motor vehicles shall display between 30 minutes after sunset and 30 minutes before sunrise, two white lights in front of sufficient power to be visible 200 feet away in the direction the vehicle is moving, and one red light visible in the opposite direction; also one rear white light which shall illuminate and make plainly visible the license number tag. Provided that motorcycles need have but one front light. (12614 G. C.)

SEC. 2 — During the same period given in Sec. 1, bicycles shall have a light of sufficient power to be seen 200 feet in the direction the bicycle is moving.

SEC. 3 — Bright lights on any vehicle or street car operated within the limits of the right of way of any road shall be dimmed or controlled while approaching and passing another vehicle so as to protect from the direct glare, the eyes of a driver 200 feet ahead and whose eyes are 5 feet above the road surface.

SEC. 4 — In order to avoid accidents and for the purpose of securing the greatest possible safeguard to human life, all drivers of horse drawn vehicles are urged and requested to display a light at night that can be seen both in front and in the rear.

ARTICLE IX — MISCELLANEOUS REGULATIONS

SEC. 1 — The unnecessary emission of dense smoke from motors is forbidden.

SEC. 2 — No horse or other domestic animal shall be allowed to run loose and unattended upon the road.

SEC. 3 — No vehicle shall be used or so loaded as to permit its load to be scattered over the road in such a way as to be objectionable to traffic or detrimental to the road. In no case shall ashes, garbage or other vegetable matter be scattered over the road surface.

SEC. 4 — No one shall ride on any vehicle without the consent of the driver.

SEC. 5 — No road shall be blocked or obstructed by any farm implements or other machinery or obstructions except when the road is legally closed for repair or construction. (13421–11 G. C.)

SEC. 6 — No person shall operate a motor vehicle while in a state of intoxication. (12626–1 G. C.)

SEC. 7 — Any special rules or regulations for any road or portion of a road which are conspicuously displayed at either end of such road or have been made known to the driver of a vehicle by a road official, shall be strictly observed by all drivers of vehicles over the road. (7246 G. C.)

SEC. 8 — Drivers of vehicles shall observe such care as is necessary to preserve the life of the road; — avoid following the tracks of a vehicle preceding them, and avoid driving in the ruts that may have started to form in the road surface.

SEC. 9 — Any person operating a vehicle or moving a load, or who is responsible for the operating of a vehicle or the moving of a load over a road in violation of any of the rules and regulations applying to such road, in addition to the fine imposed shall be responsible for all damage which said road may sustain as a result of such violation. (13421–17 G. C.)

While a good set of Traffic Rules and Regulations will be of great service to the public, yet in connection with any set of rules and regulations that may be in force, it will be necessary for drivers to exercise common sense and good judgment to avoid accidents and protect the roads. By a careful distribution of the traffic over a good road surface, roads may be made to last several times as long as they will last when all traffic concentrates in a single track. Every individual should remember that he helps build and maintain the roads regardless of the direct taxes he pays, and hence it is to his interest that the roads be used in such a way as to preserve them and render the greatest service to the general public.

APPENDIX

SEC. 6290 (G. C.) [**"Motor vehicle" defined.**] The term "motor vehicle," as used in this chapter and in the penal laws, except where otherwise provided, shall be deemed to include all vehicles propelled by power other than muscular power, except road rollers, traction engines, police patrol wagons, police automobiles, public ambulances, vehicles run upon rails or tracks, fire engines, fire trucks or other vehicles or apparatus belonging to any police department, municipal fire department, volunteer fire company or salvage company, organized under the laws of Ohio, or used by such police department, volunteer fire company, or salvage company, in the discharge of its functions or in transporting its officers, members, employes, men or articles necessary and proper for the proper discharge of such functions, to or from a fire or in response to any alarm of fire or to any other alarm or call to which it may respond. (100 v. 72; Am. 103 v. 763; 106 v. 139).

SEC. 6310 (G. C.) [**Meeting vehicle on highway.**] A person driving a carriage or vehicle on a public turnpike, road or highway, on meeting a carriage or vehicle, shall keep to the right so as to leave half of the road free for the coming vehicle.

A person riding on horseback or on a bicycle, tricycle, or tandem bicycle, or driving a locomobile, automobile, or any motor vehicle operated by its own power, on meeting a carriage or vehicle drawn by horses or oxen, shall keep to the right so as to leave one-half of the road free for the use of the vehicle drawn by horses, mules or oxen.

A person driving a carriage, vehicle, automobile, or any kind of vehicle, who desires to pass a vehicle going in the same direction on any public road or highway shall give an alarm or demand to the person or persons driving the vehicle in front and going in the same direction, of such desire, and the person so driving the front vehicle shall immediately give the half of the road to the rear vehicle, by turning to the right, so that the rear vehicle can pass to the left of the front vehicle.

[Definition; penalty.] The term vehicle herein shall apply to any vehicle propelled by its own power or drawn by horses or oxen. Any person or persons driving any vehicle, horse-drawn or otherwise, on any public road, who shall fail, in meeting or passing, to give the required road as herein stated, shall be subject to a fine in a court having jurisdiction thereof, in any sum not less than one dollar, nor more than ten dollars, and costs of prosecution. (R. S. Sec. 3490. Am. 103 v. 556).

Sec. 7246 (G. C.) **[Publication of traffic rules and regulations; special rules; enforcement.]** The state highway commissioner within sixty days after the taking effect of this act, shall prepare and publish a set of traffic rules and regulations governing the use of, and traffic on, all state roads. All rules and regulations that are to apply generally throughout the state, including those applicable to roads constructed of the various kinds of road material, shall become effective thirty days after publication. Special rules and regulations or orders, applying only to specified sections of state roads, shall become effective as soon as posted at each end, and at all road crossings on such specified section. For the purpose of carrying into effect the provisions of this section, it shall be the duty of the state highway commissioner, the county commissioners, the county highway superintendent, the township highway superintendent, township trustees, and all patrolmen or deputies employed on any highways within the state, to prosecute any violation of this section. It shall be unlawful for any person or persons, firm or corporation to enter upon, or travel over said state roads, except in accordance with the traffic rules and regulations promulgated by the state highway commissioner.

Sec. 7477 (G. C.) **[Weight of load and tire width prescribed.]** No person, firm or corporation, in a county having macadamized, graveled or stone roads shall transport over such roads, in a vehicle having a tire of less than three inches in width, a burden, including weight of vehicle, of more than thirty-four hundred pounds.

[Board of directors and duties; penalty.] The county commissioners shall constitute a board of directors for their respective counties, with power to prescribe the increased gross weight in excess of thirty-four hundred pounds that may be carried, including weight

of vehicles, in vehicles having a width of tire three inches or upwards, and cause such regulations to be recorded in their journal. Any person violating this section or any regulation duly prescribed by the board of county commissioners, made in pursuance thereof, shall be fined not less than five dollars nor more than fifty dollars.

[Enforcement of traffic regulations.] The township trustees of any township and the county commissioners of any county, shall cause to be prosecuted all persons violating this section or any regulations prescribed by the board of county commissioners made in pursuance of the authority conferred in this section. The county commissioners within their respective counties, may appoint a suitable person or persons to enforce such section and regulations. The person or persons so appointed shall receive for each conviction by them secured under this section, such portion of the fine or penalty as the commissioners deem just and proper.

SEC. 7478 (G. C.) **[Publication of traffic rules in counties.]** The state highway commissioner shall furnish the county highway superintendent with a copy of the rules and regulations promulgated by said state highway commissioner, and applicable to his county. The county highway superintendent shall cause the rules and regulations so furnished to him by said highway commissioner to be published, at least once each week, for two successive weeks, in a newspaper published and of general circulation in said county, if there be any such paper published in said county, but if there be no newspaper published in said county then in a newspaper having general circulation in said county. When such regulations are published in the manner aforesaid, it shall be deemed a sufficient publication under the provision of this act.

SEC. 12603 (G. C.) **[Operating motor vehicle unreasonably and improperly; penalty.]** Whoever operates a motor vehicle or motorcycle on the public roads or highways at a speed greater than is reasonable or proper, having regard for width, traffic, use and the general and usual rules of such road or highway, or so as to endanger the property, life or limb of any person, shall be fined not more than twenty-five dollars, and for a second offense shall be fined not less than twenty-five dollars nor more than fifty dollars. (99 v. 541, 543, Secs. 14, 25. Am. 103 v. 161).

SEC. 12604 (G. C.) **[Violation of speed limit.]** Whoever operates a motorcycle or motor vehicle at a greater speed than eight miles an hour in the business and closely built-up portions of a municipality or more than fifteen miles an hour in other portions thereof or more than twenty miles an hour outside of a municipality, shall be fined not more than twenty-five dollars, and for a second offense shall be fined not less than twenty-five dollars nor more than fifty dollars. (99 v. 541, 543, Sec. 15, 25).

SEC. 12605 (G. C.) **[Failure to stop motor vehicle when signalled.]** Whoever, operating a motor vehicle, fails to slow down and stop it when signalled so to do upon meeting or overtaking a horsedrawn vehicle or person on horseback and to remain stationary until such vehicle or person has passed, provided such signal to stop is given in good faith, under circumstances of necessity, and only

as often and for such length of time as required for such vehicles or person to pass, whether approaching from the front or rear, shall be fined not more than twenty-five dollars, and for a second offense shall be fined not less than twenty-five dollars nor more than fifty dollars. (99 v. 541, 543. Secs. 16, 25).

SEC. 12606 (G. C.) **[Failure to stop motor vehicle in case of accident.]** Whoever, operating a motor vehicle on a public road or highway, in case of an accident to a person or property thereon due to the operation of such motor vehicle, fails to stop upon the request of the person injured or a person present, give his name and address, and, if not the owner thereof, the name and address of such owner, shall be fined not more than twenty-five dollars, and for a second offense shall be fined not less than twenty-five dollars nor more than fifty dollars. (90 v. 541, 543, Secs. 16, 25).

SEC. 12607 (G. C.) **[Third or subsequent offense.]** For a third or subsequent offense, a person convicted of a violation of any provision of the next four preceding sections, shall be fined not less than fifty dollars nor more than one hundred dollars or imprisoned not more than thirty days, but if such subsequent offense occurred within one year after any former offense, he shall be imprisoned not less than ten days nor more than thirty days. (99 v. 543, Sec. 25.)

SEC. 12614 (G. C.) **[Penalty for failing to provide motor vehicle with bell, brakes, and lights.]** Whoever operates or drives a motor vehicle upon the public roads and highways without providing it with sufficient brakes to control it at all times and a suitable and adequate bell or other device for signalling, or fails during the period from thirty minutes after sunset to thirty minutes before sunrise to display a red light on the rear thereof and three white lights, two on the front and one on the rear thereof, the rays of which rear white light shall shine upon and illuminate each and every part of the distinctive number borne upon such motor vehicle, the light of which front lamps to be visible at least two hundred feet in the direction in which such motor vehicle is proceeding, shall be fined not more than twenty-five dollars. Provided, that motor vehicles of the type commonly called motor cycles shall display one white light in front to be visible at least two hundred feet in the direction in which such motor vehicle is proceeding, and one rear combination red and white light, showing red in the direction from which such motor vehicle is proceeding, and such rear light to be so placed that it will reflect its white light upon and fully and clearly illuminate the distinctive license identification mark of such motor vehicle. (99 v. 540, 543, Secs. 12, 24. Am. 103 v. 766).

SEC. 12628-1 (G. C.) **[Intoxicated person operating motor vehicle upon public highway or street, unlawful.]** That it shall be a misdemeanor for any person to operate a motor cycle or motor vehicle of any kind upon any public highway or street while in a state of intoxication, and upon conviction he shall be subject to punishment by a fine not less than twenty-five dollars, nor more than one hundred dollars, or imprisonment in the county jail for not more than six months, or both. (99 v. 544, Sec. 32. Am. 103 v. 133).

SEC. 13421-9 (G. C.) **[Driving over closed highway; penalty.]**

Whoever drives over, upon, along or across a public highway, or any part thereof, which has been closed, while in the process of construction, reconstruction or repair by order of the state highway commissioner, county highway superintendent, county commissioners, township trustees or other official or employe having authority to close such highway, shall be fined not more than fifty dollars, nor less than five dollars.

SEC. 13421–11 (G. C.) [**Placing obstruction in highway; penalty.**] Whoever unlawfully places any obstruction in, or upon a public highway, shall be fined not more than fifty dollars, nor less than five dollars.

SEC. 13421–12 (G. C.) [**Driving traction engine with destructive tires; penalty.**] Whoever drives over the improved highways of the state, or any political subdivision thereof, a traction engine with tires of wheels equipped with lugs, spikes, chains or other projections seriously destructive to such highways, or by any other means damages such highways, shall be fined for each offence not less than ten dollars nor more than two hundred dollars.

SEC. 13421–14 (G. C.) [**Digging, excavating, piling earth or building fence on highways; penalty.**] Whoever digs up, removes, excavates or places any earth or mud upon any portion of any public highway or builds a fence upon the same without legal authority or permission so to do, shall be fined not more than two hundred dollars nor less than ten dollars. Each day that such person continues to dig up, remove or excavate any portion of the public highway shall constitute a separate offence.

SEC. 13421–16 (G. C.) [**Placing nails, tacks, glass, etc., upon highway; penalty.**] Whoever places upon any part of a public highway, lane, road, street or alley, any tacks, bottles, wire, glass, nails or other articles, except such substances as may be placed there by proper authorities for the repair or construction thereof, which may damage or injure any person, vehicle or animal traveling along or upon said public highway, shall be fined not more than two hundred dollars or imprisoned not more than six months or both.

SEC. 13421–17 (G. C.) [**Violation of traffic rules; penalty.**] Whoever enters upon, or travels over any portion of the highways, within the state, in violation of the traffic rules and regulations duly prescribed by law, or the state highway commissioner, or the county highway superintendent of any county, shall be fined not more than one hundred dollars, nor less than five dollars, and in addition thereto, such person shall be liable for all damage done to such highway.

STATE OF NEW YORK
HIGHWAY COMMISSION

AMENDED RULES AND REGULATIONS FOR STATE AND COUNTY HIGHWAYS

Adopted by the Commissioner of Highways of the State of New York

SEC. 1. No traction engine, road engine, hauling engine, trailer, steam roller, automobile truck, motor or other power vehicle shall be operated upon or over State or County Highways of this State, the face of the wheels of which are fitted with flanges, ribs, clamps, cleats, lugs or spikes. This regulation applies to all rings or flanges upon guiding or steering wheels on any such vehicle. In case of traction engines, road engines or hauling engines which are equipped or provided with flanges, ribs, clamps, cleats, rings or lugs, such vehicles shall be permitted to pass over such highways provided that cleats are fastened upon all the wheels of such vehicles, not less than $2\frac{1}{2}$ inches wide and not more than $1\frac{1}{2}$ inches high, and so placed that not less than two cleats of each wheel shall touch the ground at all times, and the weight shall be the same on all parts of said cleats.

The foregoing regulations relating to flanges, ribs, clamps, cleats, rings or lugs shall not apply to traction engines used solely for agricultural purposes, but the following requirements shall apply to such traction engines:

The guide band on the front wheels shall not be less than two inches in width, but no flanges, ribs, clamps, cleats, rings or lugs shall be required upon the front wheels. The full set of cleats upon the rear wheels of the original design as furnished with the engines must be used, and no rivet heads or bolt heads shall project, and the use of such traction engines for agricultural purposes shall not permit the use for hauling purposes, excepting the hauling of threshing and other agricultural equipment necessary for threshing and agricultural purposes.

This provision shall in no case relieve the owner of any traction engines from liability for damage to roads from defective wheels.

The use also of ice picks or mud lugs shall be strictly prohibited on State and County Highways.

SEC. 2. No traction engine, trailer, steam roller, automobile truck, motor or other power vehicle shall be operated upon or over the State or County Highways of this State, nor shall any object be moved over or upon any such highways upon wheels, rollers or otherwise, in excess of a total weight of fourteen tons, including the vehicle, object or contrivance and load, without first obtaining the permission of the State Commission of Highways as hereinafter provided. No weight in excess of nine tons shall be carried on any one axle of any such vehicle.

SEC. 3. The tire of each wheel of a traction engine, road engine, hauling engine, trailer, steam roller, automobile truck, motor or other power vehicle (except traction engines, road engines, and hauling engines) shall be smooth, and the weight of such vehicle, including

load, shall not exceed 800 lbs. upon any inch in width of the tire, wheel, roller or other object, and any weight in excess of 800 lbs. upon an inch of tire is prohibited unless permission is obtained from the State Commission of Highways as hereinafter provided.

Sec. 4. No motor or other power vehicle shall be operated upon any State or County Highway of a greater width than ninety inches, except traction engines which may have a width of one hundred ten inches.

Sec. 5. No traction engine, road engine, hauling engine, trailer, steam roller, automobile truck, motor, or other power vehicle, carrying a weight in excess of four tons, including the vehicle, shall be operated upon any State or County Highway of this State at a speed greater than fifteen miles an hour; and no such vehicle carrying a weight in excess of six tons, including the vehicle, shall be operated upon any such highway at a speed greater than six miles an hour when such vehicle is equipped with iron or steel tires, nor greater than twelve miles an hour when the vehicle is equipped with tires of hard rubber or other similar substance.

Sec. 6. The State Commission of Highways of the State of New York, upon proper application in writing, may grant permission for the moving of heavy vehicles, loads, objects, or structures in excess of a total weight of fourteen tons over its State and County Highways upon proper application in writing being made therefor, and under such restrictions as said Commission may prescribe.

Sec. 7. The owner, driver, operator or mover of any vehicle over any State or County Highway shall be responsible for all damage which said highway may sustain as a result of a violation of any of the provisions of the foregoing Rules and Regulations, and the amount thereof may be recovered in an action of tort by the State Commission of Highways or by any County Superintendent of Highways of any county or by any Town Superintendent of Highways in any town in which said violation occurs.

Sec. 8. These amended regulations to take effect February 24, 1914.

"Section 24 of Chapter 25 of the Consolidated Laws, entitled 'The Highway Law,' provides that any disobedience of any of the foregoing rules and regulations shall be punishable by a fine of not less than $10, and not more than $100, to be prosecuted by the Town, County or District Superintendent, and paid to the County Treasurer to the credit of the fund for the maintenance of such highways in the town where such fine is collected."

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NOTE.—The first page number given will generally provide the data desired. The page numbers for each item are arranged in the order of importance of the reference.

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